EXPERIMENTAL AND COMPUTATIONAL ASSESSMENT OF TRACE NUCLIDE RATIOS IN WEAPONS GRADE PLUTONIUM FOR NUCLEAR FORENSICS ANALYSIS

A Dissertation

by

MATHEW WAYNE SWINNEY

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Chair of Committee,	Sunil S. Chirayath
Committee Members,	Marvin L. Adams
	William S. Charlton
	William Rundell
Head of Department,	Yassin A. Hassan

December 2015

Major Subject: Nuclear Engineering

ABSTRACT

A terrorist attack using an improvised nuclear device is one of the most serious dangers facing the United States. The work presented here is an effort to improve nuclear deterrence by developing a methodology to attribute weapons-grade plutonium to a source reactor by measuring the intrinsic physical characteristics of the interdicted plutonium. The reactor source attribution methodology attempted here used measurements and analysis of plutonium samples (along with the fission-product contaminants) produced from depleted uranium dioxide samples irradiated in a fast neutron environment. In order to replicate the neutron flux in a fast-spectrum reactor and obtain experimental samples emulating weapons-grade plutonium produced in the blanket of a Fast Breeder Reactor (FBR), depleted uranium dioxide (DUO_2) samples were placed in a gadolinium sheath and irradiated in the High-Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL). Previous computational work on this topic identified several fission products that could be used to distinguish between reactor types, specifically; ^{137}Cs, ^{134}Cs, ^{154}Eu, ^{125}Sb, ^{144}Ce, ^{85}Rb, ^{147}Pm, and ^{150}Sm along with the Pu-vector. Simulations of the fast neutron irradiation of the DUO_2 fuel samples in the HFIR were carried out using the radiation transport code, MCNPX. Comparisons of the predicted values of plutonium and fission-product concentrations to destructive and non-destructive assay measurements of neutron irradiated DUO_2 samples are presented. The agreement between the predictions and the gamma spectroscopic measurements were within ~12% for ^{134}Cs, ^{137}Cs, ^{154}Eu and ^{144}Ce. Additional experimental results (mass spectroscopy) agreed to within 5% of the Monte-Carlo simulations for the following isotopes: ^{85}Rb, ^{147}Pm, ^{150}Sm, ^{154}Eu, ^{148}Nd, ^{144}Ce and ^{239}Pu. Results obtained from simulations of an Indian Prototype FBR and a Pressurized Heavy Water Reactor (PHWR) are also compared with the results from the HFIR simulation and experiment to demonstrate a methodology implementing a straightforward maximum likelihood calculation for attributing plutonium to a source reactor.

DEDICATION

I would like to dedicate this dissertation to my wife and family. Tina, my mother, has always been my loudest supporter – I wouldn't be the man I am without your love and guidance. Thank you mom. Greg, my father, taught me to never give up – and there have certainly been times it would have been easy – but I knew that he would always be a pillar for me to lean on. Thank you dad. Shirley, my grandmother, is another source of strength that I can always count on – she would do anything to help me, without regard for herself. Thank you Grandma. Walter, my brother (in spirit), has always had my back regardless of circumstance. Thanks brother. Adrienne, my wife, is my best friend and has been with me through the best times in my life and the worst – I know that I can always count on you and look forward to coming home to you for the rest of my life. Thank you, my love. I don't know where I would be without all of my family's support – thank you all for believing in me.

ACKNOWLEDGEMENTS

I would like to thank Dr. Sunil S. Chirayath and Dr. William S. Charlton from the Nuclear Security Science and Policy Institute at Texas A&M for their support and expertise on this work. I would also like to thank Dr. Cody Folden, Dr. Tarun Bhardwaj, and Mr. Paul Mendoza for their knowledge and assistance with the chemistry required to complete this work. I would especially like to acknowledge the extra effort that Dr. Chirayath devoted to my development; it is truly rare to find a mentor so willing to devote his time to his students. I would also like to thank the rest of my committee members, Dr. Adams and Dr. Rundell, for their guidance and support throughout the course of this research.

Thanks also go to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a great experience. I would specifically like to thank Dr. Craig Marianno, Evans Kitcher, Paul Mendoza, Scott Stewart, and Paul Ward for helping me during my journey here at Texas A&M, and for their friendship.

Finally, I would like to acknowledge the funding support for this project from a joint NSF and DHS ARI program (NSF Grant No. ECCS-1140018 and DNDO-2012-DN-077-ARI1057-02&03) to carry out this research.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

I. INTRODUCTION

For more than a decade, the United States leadership has consistently claimed that a terrorist attack using an Improvised Nuclear Device (IND) is one of the most serious dangers facing the country. A single IND detonating in one major city could cause a huge loss of life and have a catastrophic impact economically throughout the world.[1] In response, a significant amount of work has been directed at employing material protection and control systems, setting up networks to detect nuclear smuggling activities, and implementing additional detection mechanisms at domestic and international ports-of-entry. The Nuclear Forensics and Attribution Act (2010) also identified the need for and efficacy of a robust nuclear forensics capability, through which the threat of attribution could serve as a strong deterrent to prospective proliferators.[2,3] A State's ability to interdict Special Nuclear Material (SNM) smuggling and to establish the forensics expertise for attributing the origin of the material (source attribution) are both highly desirable deterrence features. These features not only aid in curbing an adversary's malicious attempts, but also in restraining rogue States from supplying SNM to sub-state actors due to the fear of retaliation. By providing a strong incentive to a government to maintain and secure its SNM, it may be possible to deter a sub-national group from seeking or obtaining a nuclear weapon.[4] A secondary application of this work could be in the field of safeguards as a supplement to traditional materials control and accountability programs. In the unlikely event that material could not be identified via simpler means, the forensics methodology discussed in this work could be used to help classify misplaced or unknown material.

This work focuses on developing a methodology for the source attribution of plutonium, a byproduct in used nuclear fuel, which is bred in nuclear reactors by the conversion of uranium in the fuel. The plutonium isotope of interest in weapons-grade material is ^{239}Pu and is produced by the neutron capture by the uranium isotope ^{238}U to convert it initially into ^{239}U and subsequently to ^{239}Np and finally into ^{239}Pu through two beta particle decays, as seen in Eq. (1).

$$ {}^{238}_{92}U + {}^{1}_{0}n \xrightarrow{(n,\gamma)} {}^{239}_{92}U \xrightarrow{\beta^-} {}^{239}_{93}Np \xrightarrow{\beta^-} {}^{239}_{94}Pu \tag{1}$$

Fuel burnup is defined as the thermal energy produced in the nuclear fuel per unit mass of initial heavy metal, typically described using the unit of measurement gigawatt-days per metric ton of uranium (GWd/MTU). As this burnup increases, some of the ^{239}Pu undergoes fission reactions and some absorbs neutrons, producing successive isotopes of plutonium such as ^{240}Pu, ^{241}Pu, and ^{242}Pu. ^{238}Pu is also produced as seen through the reaction chains shown in Eq. (2) and Eq. (3). The concentration of the ^{239}Pu isotope in the plutonium determines the plutonium grade; such as super-grade, weapons-grade, or reactor grade, the higher concentrations being better for weaponization purposes.[5] Table 1 illustrates some examples of the various grades of plutonium.

$$ {}^{235}_{92}U + {}^{1}_{0}n \xrightarrow{(n,\gamma)} {}^{236}_{92}U + {}^{1}_{0}n \xrightarrow{(n,\gamma)} {}^{237}_{92}U \xrightarrow{\beta^-} {}^{237}_{93}Np + {}^{1}_{0}n \xrightarrow{(n,\gamma)} {}^{238}_{92}Np \xrightarrow{\beta^-} {}^{238}_{94}Pu \tag{2}$$

$$ {}^{238}_{92}U + {}^{1}_{0}n \xrightarrow{(n,2n)} {}^{237}_{92}U \xrightarrow{\beta^-} {}^{237}_{93}Np + {}^{1}_{0}n \xrightarrow{(n,\gamma)} {}^{238}_{92}Np \xrightarrow{\beta^-} {}^{238}_{94}Pu \tag{3}$$

Table 1 Approximate isotopic composition of various grades of plutonium[5]

Grade	Isotope (%)				
	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu
Super-grade	-	98	2	-	-
Weapons-grade	.01	94	5.8	.35	.02
Reactor-grade	1.3	60	24	9.1	5.0
MOX-grade	1.9	40	32	18	7.8
FBR blanket	-	96	4	-	-

Typically, the production of weapons-grade plutonium is achieved by keeping the fuel burnup levels less than ~5 GWd/MTU, usually closer to 1 GWd/MTU. A fast breeder reactor, for example, has the potential to produce weapons-grade plutonium through normal operation, specifically in the blanket material (Depleted Uranium diOxide – DUO_2) located at the periphery of the reactor core to absorb the neutrons leaking from the fuel region. Plutonium thus produced can be separated from other major actinides (uranium), minor actinides (neptunium, americium, etc.), and fission products (cesium, europium, ruthenium, etc.) in the used fuel using a chemical process such as Plutonium Uranium Redox EXtraction (PUREX).[6]

The main objective of the work presented in this dissertation was to determine the feasibility of using trace nuclide contamination in separated weapons-grade plutonium as an intrinsic physical characteristic for nuclear forensics purposes to distinguish between plutonium produced in fast reactor blanket material from that produced in thermal reactor fuel. This is accomplished by using computational simulations as well as by performing pertinent experimental measurements to confirm and demonstrate the attribution methodology.

To obtain meaningful experimental results, an irradiation of DUO_2 samples (fast reactor blanket material) to a low burnup (< 5 GWd/MTU) had to be carried out in a fast neutron environment inside a suitable reactor. Since the investigators did not have access to a fast reactor to carry out such an experimental study, the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL), which is a thermal-spectrum reactor, was selected for carrying out the neutron irradiation of DUO_2 samples. In order to obtain a fast neutron environment in the HFIR, a special irradiation capsule design was used.

The final research objective of this study was to propose nuclear forensics steps to be followed for source attribution in the event of plutonium interdiction. Although the attribution methodology could be applied to various reactor types (and should be), the particular reactors of interest in this work are the Fast neutron spectrum Breeder Reactors (FBRs) of the type under development in India and China, which employ DUO_2 in their core blankets, and the Pressurized Heavy Water Reactor (PHWR) type fueled by natural UO_2.[7-14] It is likely that both of these reactor types will be operated in countries developing nuclear power in the future, and both reactor types have proliferation concerns. Specifically, PHWR reactors are refueled on-line, and could eject irradiated fuel early to generate weapons-grade plutonium. For example, the Indian PHWR produces ~130 kg of plutonium with an average burnup of 7 GWd/MTU per year.[8] If the fuel bundles were ejected early to produce weapons-grade plutonium, this would likely produce more than 6 significant quantities (SQs as defined by the IAEA)[15] per year. Also, in general, the design aspects of a typical sodium-cooled FBR require that the main core be refueled about every six months; during this six-month period, DUO_2 in the blanket region will experience a low burnup of about 1 GWd/MTU, an ideal burnup for generating high quality weapons-grade plutonium. For example, previous work has estimated that India's 500 MWe Prototype Fast Breeder Reactor (PFBR) will produce about 140 kg, or over 17 SQs, of weapons-grade plutonium in the blankets of the reactor each year.[9,11]

When developmental FBRs begin operating in the near future, it would be beneficial to understand the details of characteristics associated with plutonium produced from DUO_2 in the FBR blanket. Understanding of any features characteristic of specific reactor types, such as the Pu isotopics, residual uranium isotopics, fission-product and trace elemental contaminant concentrations in separated Pu from fuel could aid nuclear forensics activities aimed at source attribution if plutonium is interdicted. Both of the reactor types mentioned will likely be operating in non-safeguarded circumstances in the future, and the ability to define a measurable characteristic which could be used for reactor type source attribution of plutonium may provide an effective deterrent. The research conducted focused on the following:

(a) Specific nuclear reactor core burnup simulations and analysis,

(b) Neutron irradiations of samples of depleted uranium dioxide (DUO_2) in a fast neutron spectrum,

(c) Investigation of irradiated DUO_2 samples through gamma and mass spectroscopic measurements,

(d) Comparison of simulation results with the experimental measurements (gamma and mass spectroscopy) of isotopic concentrations in neutron irradiated DUO_2 samples, and

(e) Proposing nuclear forensics steps that may be followed for the source attribution in the event of plutonium interdiction.

The first step in the project was accomplished by developing a Monte-Carlo model with the well-known neutronics code MCNPX and CINDER90 to simulate the irradiation of the DUO_2 samples in a fast neutron flux. This step was crucial for three reasons: first, to validate the predictive capabilities of the method with experimental results; second, to compare the irradiation conducted at the HFIR to the hypothetical irradiation of a fast breeder reactor blanket; and finally, to serve as a data point for the ‘library’ used in the final comparison methodology. The comparison to experimental results will establish confidence in the method and the simulations, while the comparison between the HFIR and FBR models will establish how representative the physical samples produced through this work are of material that would be recovered from an FBR blanket.

The next step was to irradiate DUO_2 fuel samples in a fast neutron spectrum, ideally to a low burnup (<5 GWd/MTU) in order to produce weapons-grade plutonium. The irradiation was carried out at ORNL in the HFIR primarily due to the extremely high neutron flux within the central flux trap region (~$2x10^{15}$ n/cm^2 s). Because a gadolinium sheath was used as a ‘high-pass’ neutron filter to create a fast neutron spectrum, a substantial fraction of the thermal neutrons are absorbed before reaching the fuel samples. In order to get the irradiation time down to a couple of months, a high initial neutron flux was needed.

Following the irradiation, the fuel samples were dissolved in a glove box at Texas A&M Nuclear Science Center and interrogated with both NDA (gamma-spectroscopy) and DA (mass-spectroscopy) methods. After this initial characterization, the samples underwent a lab-scale PUREX process at a radio-chemistry laboratory located at the Texas A&M Nuclear Engineering Department. Once the chemical separation was completed, the samples were re-measured using both NDA and DA methods.

After all of the simulation and experimental measurements, results were analyzed and compared. A methodology was developed for comparing the experimental results to a simulation ‘library’, thus demonstrating how the methodology could be used to attribute the source of the material. The preliminary methodology presented here uses a fairly straightforward comparison scheme and a ‘library’ that is far too under-populated – an extremely robust library would need to be created before any meaningful conclusions could be drawn in a real-world situation.

In summary, the objective of the study presented here is to characterize the plutonium isotopics and trace fission-product contamination in plutonium separated from low-burnup blanket fuel material (DUO_2) irradiated in a fast neutron spectrum. The work involves computational reactor core burnup calculations to simulate the neutron irradiation of DUO_2 samples representative of FBR blanket material at the Oak Ridge National Laboratory High-Flux Isotope Reactor (ORNL-HFIR) and the experimental investigations of neutron-irradiated DUO_2 samples at Texas A&M. Information on the trace fission-product contamination and the plutonium isotopics will be very valuable for nuclear forensics analysis aimed at attributing material to a source reactor; specifically a somewhat less ubiquitous reactor, like the proposed FBR. Ultimately, the goal of this work was to determine if trace fission-product contamination quantification can be used to identify the source of separated, weapons-grade plutonium, and if so, to propose a preliminary methodology to attribute an unknown sample of plutonium.

A literature review of current nuclear forensics methodologies was conducted, and a survey of the results is presented in Chapter II. Discussions of the experimental and computational methodologies used in this work are presented in Chapter III. This includes a brief description of the Monte-Carlo radiation transport and fuel burnup codes used (MCNPX/CINDER90) and both the non-destructive and destructive assay (NDA and DA) techniques used to characterize the fuel samples. Chapter IV details the simulation work completed, outlining the model used along with the associated results. Chapter V presents the details of the gamma spectroscopy experiments as well as the results from destructive mass-spectroscopy measurements. Chapter V also compares the computational and experimental results, identifying how well they agree. Finally, Chapter VI outlines some preliminary forensics steps that include proposed measurements and comparison methodology that could be used for the source attribution of plutonium in an event of interdiction. This chapter also discusses some of the future work that should be carried out to compliment and continue this effort.

II. SURVEY OF CURRENT NUCLEAR FORENSICS METHODS

Although nuclear forensics is a relatively new field, a large body of work has been conducted with a focus on nuclear safeguards verification techniques[16], characterization of spent (used) fuel[17], the source attribution of SNM[18,19], age-dating[20-22], and introductions/overviews of the typical techniques used in the field.[23-28] However, most of the research available in open literature has focused only on high burnup reactor fuels, plutonium and actinide isotopics, and thermal (water or graphite moderated) reactors.[29,30] The presented work is unique due to its focus on using trace fission-product ratios in low burnup weapons-grade plutonium produced in an FBR.

II.A. Plutonium Vector as Forensics Characteristic

The different plutonium isotopes present in irradiated nuclear fuel (^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{242}Pu) constitute the Pu vector, which is one of the characteristics currently thought to be useful for the source-reactor attribution of plutonium. Figure 1 illustrates the primary pathways by which each of these isotopes of plutonium is populated in nuclear fuel. It is clear that various reactions and their time dynamics will contribute to the final makeup of the Pu vector. Fuel burnup will be one of the primary factors: as ^{239}Pu builds up in the fuel (or blanket) of the reactor, it also becomes a target, capturing neutrons to form the heavier plutonium isotopes. However, some of the neutron-capture reactions are very energy-sensitive, which will lead to a dependence on the neutron energy spectrum, which is very strongly correlated to the reactor type. There will also be a dependence on the starting fuel, which will also be an indicator of the type of reactor that produced the plutonium.

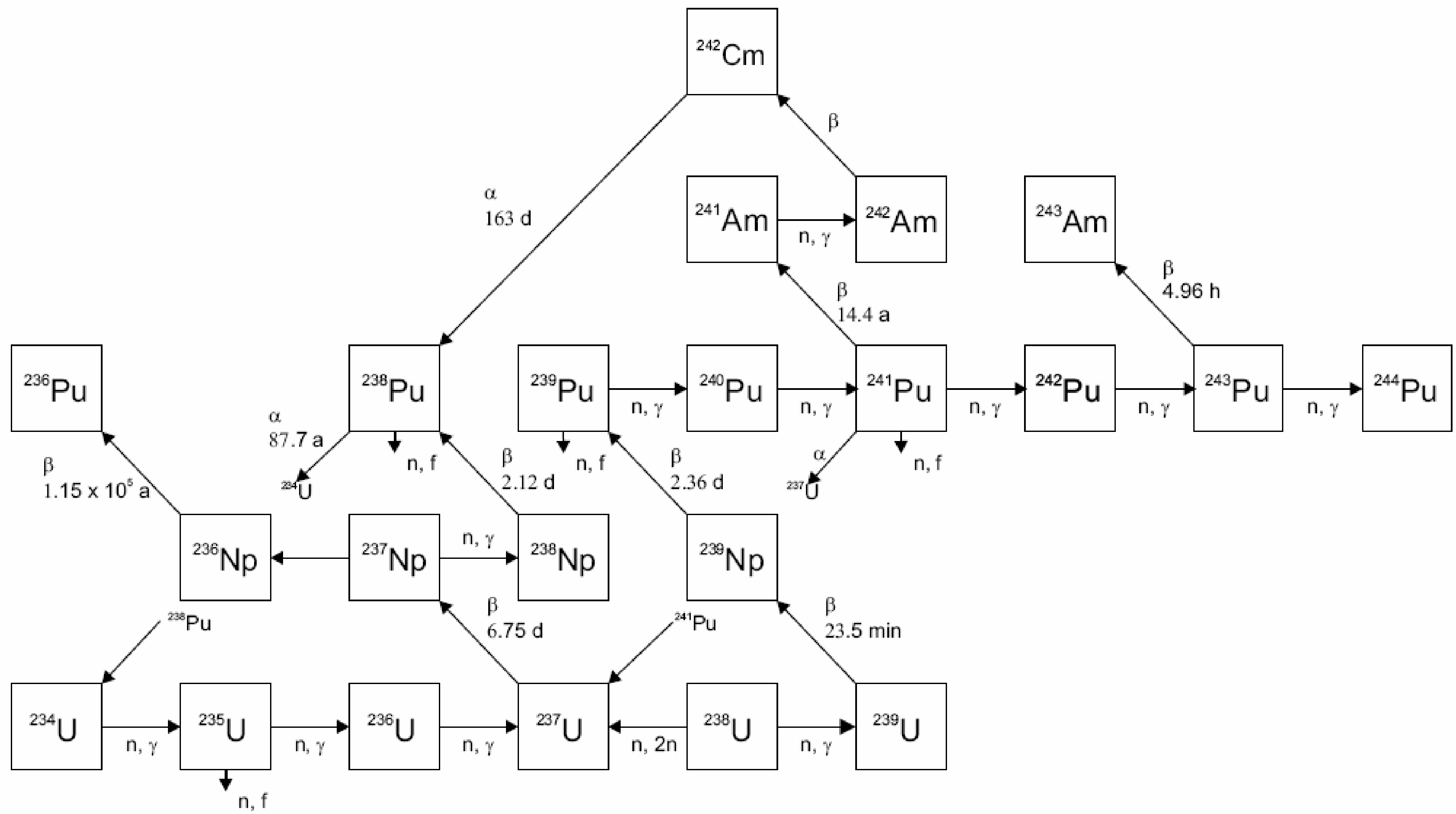


Figure 1: Production and decay scheme of plutonium isotopes.[26]

The Pu vector is characteristic of the irradiation conditions and can be determined through a combination of alpha, gamma, and/or mass spectroscopy. The most important isotope is ^{239}Pu, but ^{238}Pu is also important, since it gives information on the high-energy component of the irradiating neutron spectrum (the $^{239}Pu(n, 2n)^{238}Pu$ reaction has a threshold energy of 5.67 MeV). The heavier Pu isotopes provide information on the low-energy portion of the neutron spectrum, since they are produced by neutron-gamma reactions with no threshold energy. Unfortunately, the alpha radiation energies of ^{239}Pu and ^{240}Pu are very similar and cannot be resolved with a typical alpha detector, although the sum of their activities can be obtained. The $^{239}Pu/^{240}Pu$ isotope ratio can be resolved with mass spectrometry.

As mentioned, the concentration of the ^{239}Pu isotope in the plutonium determines how suitable the plutonium is for use in a nuclear weapon – the higher the concentration, the more suitable the plutonium is for use in an explosive device. The production of weapons-grade plutonium is typically achieved by keeping the fuel burnup around 1 GWd/MTU, comparable to the typical burnup reached in a blanket DUO_2 assembly of an FBR. The concentration of ^{239}Pu relative to the other isotopes in the resultant plutonium also holds information about the irradiation environment. In brief, the Pu vector characteristics depend primarily on the amount of fuel burnup, the nature of the neutron energy spectrum to which the fuel was exposed, the make-up of the fuel itself, and the amount of time since the irradiation occurred. Typical examples of the Pu vector for used fuel from a few reactor types based on computations are listed in Table 2.[6,14,31,32] This table shows that the Pu vector characteristics are different depending on the burnup and the reactor type.

Table 2 Plutonium vector characteristics of irradiated nuclear reactor fuel

Plutonium Isotope	PHWR Reactor (7.5 GWd/MTU)	PWR (33 GWd/ MTU)	FBR Blanket (1 GWd/ MTU)	CANDU Reactor (1 GWd/ MTU)
^{238}Pu (wt %)	0.08	1.60	0.01	0.00
^{239}Pu (wt %)	69.34	60.07	98.72	94.23
^{240}Pu (wt %)	25.9	24.3	1.26	5.48
^{241}Pu (wt %)	3.37	8.82	0.01	0.28
^{242}Pu (wt %)	1.32	5.21	0.00	0.01

The first two columns in Table 2 represent two common reactor types (PHWR and Pressurized (light) Water Reactors (PWRs)) at representative average fuel discharge burnups for each type. The last two columns show that even if the fuel burnup for both the FBR and the CANDU cases is 1 GWd/MTU, the Pu vector can be different. This difference primarily results from the reactor design (and hence the neutron energy spectrum), but it is also affected by the type of fuel irradiated in the FBR (depleted uranium dioxide with 0.25% ^{235}U and 99.75% ^{238}U) compared to the CANDU reactor (natural uranium dioxide with 0.71% ^{235}U and 99.29% ^{238}U). Note that the Pu vector listed for an average CANDU burnup (7.5 GWd/MTU) and for an average PWR burnup (33 GWd/MTU) for normal power production operations are both reactor-grade (^{239}Pu ~ 50 to 70%). However, the Pu vector resulting from the average burnup (1 GWd/MTU) in the blanket of a typical FBR and for CANDU fuel burned to 1GWd/MTU are both weapons-grade (^{239}Pu > 94%).[5]

The above discussions (based on MCNP[33]-ORIGEN2.2-Monteburns and MCNPX[34]/CINDER90 computations) illustrate that high quality weapons-grade plutonium will be produced if uranium is subject to a low burnup of about 1GWd/MTU, irrespective of the reactor type in which the uranium is irradiated. It is also apparent that the Pu vectors for the case of the FBR blanket and the low-burnup CANDU fuel while both weapon-grade qualities can be distinguished from each other based on their isotopic composition. Although the Pu vector can be a strong indicator for the determination of a source reactor, the inclusion of trace fission products can only strengthen the analysis. This is the objective of the present work.

II.B. Previous Nuclear Forensics Studies

Klaus Mayer, in his article entitled *Nuclear Forensics: A Methodology Applicable to Nuclear Security and to Non-proliferation*, defines nuclear forensics as a methodology that aims at re-establishing the history of nuclear material of unknown origin.[26] The article continues to say that it is based on the indicators that arise from known relationships between material characteristics and process history – illustrating that nuclear forensics includes the characterization of the material and correlation with production history. Most of the works cited in this dissertation, including the methodology presented within, attempt to make use of parameters such as isotopic composition and knowledge of reactor systems to draw meaningful conclusions about the materials' (or hypothetical materials) production history.

The article by Klaus Mayer[26] is one of the limited numbers of studies openly available that attempted to attribute the source of actual material used in a nuclear weapons program. Two samples presumed to be linked to the German nuclear program in the 1940's were investigated using various types of mass spectrometry (MS) (Resonance Ionization MS (RIMS), Thermal Ionization MS (TIMS), Inductively Coupled Plasma MS (ICP-MS), and Accelerator MS (AMS)). Using these measurement techniques and an age dating calculation utilizing the $^{234}U/^{230}Th$ ratio (also presented in the Journal of Analytical Atomic Spectrometry), the investigators were able to confirm the suspected production dates in the early 1940's. The study was also able to confirm that neither sample was exposed to a significant neutron fluence by using the $^{239}Pu/^{238}U$ ratio. Several other studies can be found that illustrate how age dating could be used on plutonium. This is just one example of how nuclear forensics could be useful in attributing special nuclear material.

There have been several studies looking at post-detonation material, such as A.J. Fahey's *Postdetonation Nuclear Debris for Attribution*[35], where the investigators analyze so called "trinitite" debris left from the explosion of the first U.S. nuclear weapon test, Trinity. Although interesting, the post-detonation forensics problem is significantly different than the pre-detonation scenario and must take in to account various other factors including weapons design, weapon components, and nearby debris that gets incorporated in to the fireball and distributed as fallout.

One of the examples of a study where the investigation of non-traditional isotopes is undertaken is a paper by J. Weaver[30]. In this paper, the investigators outline how certain isotopes could be used as possible signatures (Sr, Cd, Xe, Sm, Kr, Ce, Nd, etc.), indicating a difference between short and normal reactor operations. Some of these isotopes aren't applicable to the problem of separated plutonium because they would be released almost entirely during the chemical separation due to their volatile nature (Xe and Kr). Some of these isotopes are similar to the ones investigated in this work (Sm, Ce, Nd, etc.), however, they are used only to indicate whether the fuel was exposed to a normal irradiation cycle or to a much shorter irradiation cycle. This technique couldn't be used to determine what reactor type interdicted plutonium originated from – it is truly meant for a more safeguards implementation; confirming or contradicting the declared operational history of a known reactor.

Other work with the similar goal of improving safeguards by W. Charlton[16,36] outlines a technique designed to verify operator declarations at reprocessing facilities. The proposed technique involves measuring the isotopic ratios of stable noble fission-product gases from emissions during the reprocessing of spent (used) fuel using mass spectrometry. It is shown that the relative concentrations of these isotopes depend on several reactor operating conditions that could be compared to a database of ratios to determine specific fuel parameters such as burnup, reactor type, etc. The database of ratios was created using a series of reactor analysis codes to model several types of reactors. The computational modeling showed that the specific ratios of these fissiogenic noble gases could be used to distinguish among light water reactors, heavy water reactors, and breeder reactors. This proposed technique for verifying reactor operator declarations utilizes the fact that the noble gases are volatile and not chemically bound to the fuel – meaning that they are readily released during reprocessing, making these specific ratios relatively useless for analyzing post-processed materials. However, this work does demonstrate that fission-product concentrations carry information that can be used to infer a source reactor, and illustrates a methodology similar to the work presented herein.

A study conducted by Glaser[10] investigated the isotopic signatures of weapons-grade plutonium produced in several reactors that have been historically used in nuclear weapons programs (Hanford, NRX, and Calder Hall types). The Pu vector was obtained from computational models and was compared among the different reactors. The conclusion of this work was that the Pu vector could be used to distinguish basic reactor types including FBRs, PHWRs, and Light Water Reactors (LWRs). While this forensics methodology is promising, it ignores any additional information that could be collected from the fission-product concentrations. A robust methodology incorporating both the Pu vector and other sources of information would be the most beneficial in ensuring the accuracy of source attribution of interdicted plutonium.

There are numerous published studies that have developed techniques for analyzing SNM which can indicate certain parameters relevant to its origin – including burnup, reactor type, and fuel type. However, most of this research has focused on (typically thermal) reactor spent fuel, irradiated to a burnup typical of commercial reactors, where the final plutonium is reactor-grade. This dissertation investigation focuses on using isotopic characteristics of fission-product contaminants in weapons-grade plutonium that originated from reactor fuel that was irradiated to a low burnup. The result of the presented work is a methodology that uses ratios of fission-products to plutonium in weapons-grade plutonium to attribute material to a source reactor.

II.C. Basis for Current Work – Using Trace Fission Products

Two recent thesis studies conducted by Jeremy M. Osborn and Taylor M. Coles at Texas A&M University utilizing computational core burnup simulations identified several possible trace fission-product ratios that could be used to distinguish plutonium produced in a PHWR versus that produced in an FBR.[37-39] In these studies, detailed three-dimensional models of two example reactors (Indian FBR-500MWe and PHWR-220MWe) were made using the Monte-Carlo radiation transport code, MCNPX, for neutronics analysis coupled with the burnup/depletion code, CINDER90, for isotope generation/depletion computations. MCNPX is a well validated transport code that also has an excellent continuous neutron energy cross section data library derived from the evaluated nuclear data file, ENDF/B-VII.

These computer code simulations provided an estimate of the Pu vector and potential signatures from fission-product contaminants that would be expected in the separated plutonium obtained from the used fuel discharged from a PHWR-220MWe reactor and the blanket material from an FBR-500MWe discharged at a low burnup of 1 GWd/MTU. The data presented in Table 3 represents the culmination of this previous work, including several identified fission products that could be used to distinguish between the two reactor types, specifically; ^{137}Cs, ^{134}Cs, ^{154}Eu, ^{125}Sb, ^{144}Ce, ^{85}Rb, ^{90}Sr, ^{148}Nd, ^{147}Pm, and ^{150}Sm, along with the Pu vector.

Table 3 Potential trace fission-product nuclides that could be used as a signature that were identified from the previous PHWR reactor and FBR simulations

Candidate Nuclide	$\frac{(\textbf{Nuclide mass per 1 kg Pu from CANDU})}{(\textbf{Nuclide mass per 1 kg Pu from FBR})}$
Gamma Spectrometry	
^{137}Cs	12.86
^{144}Ce	28.80
^{134}Cs	3.16
^{125}Sb	5.93
^{154}Eu	3.72
Alpha Spectrometry	
^{239}Pu	0.98
^{242}Pu	19.77
Mass Spectrometry	
^{85}Rb	19.00
^{90}Sr	22.29
^{148}Nd	12.51
^{147}Pm	15.48
^{150}Sm	107.99

The proposed nuclides are grouped according to the suggested measurement method; gamma, alpha, or mass spectrometry. The given ratios next to each nuclide represent the 'signal' so to speak, or the expected factor difference in each isotope between the two investigated reactor systems. The further the ratio is from unity, the larger the difference in the fission-product to plutonium ratio between the two reactors.

The research presented hereafter was a direct experimental follow up on Osborn's thesis study investigating the characteristics of plutonium isotopic and fission-product contaminants in plutonium separated from FBR blanket material. This included the irradiation of depleted UO_2 fuel samples (representative of FBR blanket material) in a fast neutron environment followed by gamma and mass spectroscopic measurements and a bench-scale chemical separation process similar to the industrial PUREX process.

III. METHODOLOGY

This work involves both modeling and simulation work in conjunction with experimental measurements to validate the models and demonstrate the proof of concept for the proposed forensics approach. The modeling was carried out with the Monte-Carlo radiation transport code, MCNPX, which includes the fuel burnup and depletion code package, CINDER90. The experimental work included gamma spectroscopy using a High-Purity Germanium (HPGe) detector and mass spectroscopy using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). This chapter will introduce the basics of the Monte-Carlo method, both the MCNP and CINDER90 code packages, gamma spectroscopy using a HPGe detector, and ICP-MS.

III.A. The Monte-Carlo Method

Most modeling codes can be classified as either stochastic (Monte-Carlo) or deterministic. Deterministic methods, for example the discrete ordinates method or the method of characteristics, solve the Boltzmann Transport Equation (BTE) for the average particle behavior. These methods typically visualize the entire phase space (position, energy, angle, etc.) to be divided into many small cells, and the particles move from one cell to another. Deterministic methods characteristically give fairly complete information about the solution throughout the phase space of the problem. In contrast, Monte-Carlo methods simulate individual particle histories and record some aspects of interest from their average behavior by simulating a large number of particle histories. This method is a numerical technique that uses random sampling procedures to construct the solution of a physical problem. A stochastic model is setup and, by sampling from appropriate probability distributions contained in the BTE, an estimate of the required answers are computed using Monte-Carlo radiation transport simulations of a large number of particle histories. The average behavior of particles in the physical system is inferred (using the central limit theorem) from the behavior of a substantially large population of simulated particles. This method typically solves only for information relevant to the specific quantities in question, like cell or surface particle fluxes in only a part of the phase space.

The Monte-Carlo method utilizes a robust random number generator (similar to throwing dice in a game of chance, giving rise to the name "Monte-Carlo") to sample probability distributions dependent on radiation transport data specific to the problem being solved to predict nuclear interactions and behavior in the system modeled. Like most Monte-Carlo codes, MCNPX uses algorithms called linear congruential generators (LCG) to produce random numbers. The stride for this algorithm within MCNPX, or the number of random numbers assigned to track any one particles history, is 152,917 by default but can be changed by the user. The standard 48-bit LCG algorithm in MCNPX has a period of 7×10^{13} that can be extended to use up to 63 bits to extend this period to 9.2x10.[40]

As the particle is tracked, a random sampling of the appropriate probability distribution determines the outcome of each step in its life; these various interactions could be scatter events, non-events (traveling into a new cell), fission, radiative capture, or leakage from the system. Probability distributions are randomly sampled using transport data to determine the outcome of each step of its life. Typically numbers between 0 and 1 are selected randomly to determine what and where interactions take place, based on the rules (physics) and probabilities (transport data) governing the process and materials involved. The random number generator will determine the distance traveled to the next interaction based on the interaction cross-section of the medium, the collision nuclide selection, the type of reaction, direction of travel, etc. Because this is a stochastic process, many particles must be tracked, and typically, the more histories that are simulated, the more precise the results will be. Although the results may be more precise, the computation is only solving the model problem defined by the user; there will inevitably be errors associated with the geometry and materials. Even beyond these, there will also be errors associated with uncertainties in the fundamental nuclear data, such as cross sections and fission yields. However, if used properly, Monte-Carlo simulations can be powerful tools that indirectly solve the BTE by simulating individual particles and utilizing the fact that as the number of histories becomes large, the average (sample mean) behavior tends toward the population mean of the solution distribution.

Monte-Carlo modeling is well suited for solving complicated three-dimensional, time dependent problems, which makes it a reasonable choice for this research. One of the most widely used codes of this type is the Monte-Carlo N-Particle (MCNP) code developed by Los Alamos National Laboratory. The MCNP suite of codes is generally considered to be highly accurate and is used as a benchmarking resource across the nuclear engineering field.

III.B. MCNPX

The modeling and simulation work completed for this research used MCNPX Version 2.7, a general purpose, continuous-energy, generalized-geometry, time-dependent, coupled neutron/photon/electron Monte-Carlo radiation transport code. MCNPX added many features to MCNP5, specifically built in depletion capabilities by utilizing the CINDER90 depletion code. To utilize this code, a user creates an input file (sometimes referred to as a ‘deck’) that contains information regarding the geometry of the problem, a detailed description of the materials and selection of cross-section evaluations, the location and characteristics of the neutron source, and the format and content of the desired output. The code treats an arbitrary three-dimensional configuration of materials in cells bounded by first and second degree surfaces and fourth-degree elliptical tori. The cells are defined by the intersection, union, or compliments of the regions bounded by the various surfaces. The most common output from a single radiation transport calculation is a neutron flux tally averaged over a volume, over a surface, or at a point. In the case of a depletion problem, this neutron flux can be used to calculate the isotope generation and depletion in a given material.

One major benefit of using CINDER in MCNPX is that it only requires an extra BURN card to be added to a standard MCNP input deck – simplifying the implementation. Cell volumes containing fissile material as well as materials that are to be depleted need to be identified within the input file. The basic operation of the code includes a radiation transport calculation step (using MCNPX) to determine neutron fluxes and then a depletion step (using CINDER90) – these steps alternate until the number of desired burn steps is achieved per the target burnup supplied by the user. CINDER uses Markov chains to solve the series of differential decay equations, unlike ORIGEN (a popular depletion code developed by ORNL) which uses the matrix exponential method. Another convenience of the CINDER code in comparison to other depletion packages is that it allows for the user to simply state the isotopes that will be tracked throughout the transport and depletion. Tier 1 is a basic list comprised of the most common fission-products, Tier 2 adds additional fission products and actinides, and Tier 3 adds a very large list of isotopes. Due to the nature of this project, Tier 3 fission products (up to 3600 nuclides can be tracked) were implemented.

III.C. CINDER90 Depletion

CINDER90 is a FORTRAN program coupled with an extensive data library used to calculate the evolution of a nuclide inventory.[41] The original CINDER code was developed in 1960 at Bettis Atomic Power Laboratory in support of thermal reactor-fuel simulations.[42] Initially, it required the preset formation of a consistent set of linear decay chains to describe the creation and transmutation paths. All versions have used decay and energy integrated reaction rate probabilities along with fission yield information to calculate the temporal nuclide buildup and depletion. The more recent versions improved the data evaluations, fission set yields, and decay information as more reliable data became available.

The evolution that yielded CINDER90 arose from the need of the LANL accelerator group to have a more complete calculator for nuclide inventories. This upgrade included isotope decay and interaction probability data for 3456 isotopes including 30 fission yield sets, and yield data for 1325 fission-products.[43] The CINDER90 computation process involves utilizing linear Markovian chains to determine the time dependent nuclide inventories, solving for the independent contributions to nuclide densities in each of several linear nuclide chains. CINDER90 differs from earlier versions in that earlier version required a library of transmutation chains prior to a calculation. These chains were determined by what the user considered to be sufficient for the problem – but chains for one problem were not applicable to others. CINDER90 uses a library of basic nuclear data to trace all possible transmutation paths and each nuclide concentration is examined to determine whether the chain should be terminated based on a given significance criteria.

CINDER90 implements a simplification of a form of the Bateman equations in order to calculate the time-dependent nuclide densities:[44]

$$\frac{dN_m}{dt} = -N_m(t)\beta_m + \bar{Y}_m + \sum_{k\neq m} N_k(t)\gamma_{k\to m} \tag{4}$$

- dN_m/dt = rate of change in nuclide m concentration
- $-N_m(t)\beta_m$ = destruction of nuclide m
- $\sum_{k\neq m} N_k(t)\gamma_{k\to m}$ = creation of nuclide m via other nuclides in the system
- $\bar{Y}_m$ = production of nuclide m via an external source

$$\beta_m = \lambda_m + \sum_r \int \sigma_{m,r}(E)\phi(r,E,t)dE \tag{5}$$

$$\gamma_{k\to m} = \sum_{m\neq k} L_{km}\lambda_k + \sum_{m\neq k}\sum_r \int Y_{km,r}(E)\sigma_{k,r}(E)\phi(r,E,t)dE \tag{6}$$

- λ_m= destruction of nuclide m by radioactive decay
- $\sum_r \int \sigma_{m,r}(E)\phi(r,E,t)dE$ = destruction of nuclide m by transmutation reaction
- $\sum_{m\neq k} L_{km}\lambda_k$ = creation of nuclide m by another isotope radioactively decaying
- $\sum_{m\neq k}\sum_r \int Y_{km,r}(E)\sigma_{k,r}(E)\phi(r,E,t)dE$ = creation of isotope m by some isotope transmuting to isotope m via a transmutation reaction, r

Equation 4 relies on the assumption that the transmutation probabilities remain constant for the time interval in which a solution is desired. The differential equations utilized to solve for temporal nuclide burnup/depletion is coupled since each equation contains time-dependent isotope concentration information from other nuclides. In CINDER90, this set of coupled equations is reduced to a set of linear equations using the Markov method. Linear chains are created for each isotope transmutation path, and the solution of each linear chain determines a partial nuclide density, N_i. Each of these partial nuclide densities is then summed to obtain the total nuclide inventory, N_m. The equation governing the computation of N(t) is therefore only coupled to any preceding elements in the sequence leading to the i^{th} element. For the preceding (i-1) element, all the parameters are assumed known. The computation can then be completed using a simplified equation:

$$\frac{dN_i}{dt} = \bar{Y}_i + N_{i-1}(t)\gamma_{i-1} - N_i(t)\beta_i \tag{7}$$

where quantities are now indexed by the order in which they appear within the sequence and γ_{i-1} is the transmutation probability of forming nuclide element N_i. The solution form of a linear sequence of nuclides coupled by any sequence of absorption or decay, first derived and implemented by the CINDER code, was:

$$N_n(t) = \sum_{m=1}^{n} \prod_{k=m}^{n-1} \gamma_k \left\{ \bar{Y}_m \left[\frac{1}{\prod_{l=m}^{n} \beta_l} - \sum_{j=m}^{n} \frac{e^{-\beta_j t}}{\prod_{i=m,\neq j}^{n} (\beta_i - \beta_j)} \right] + N_m^0 \sum_{j=m}^{n} \frac{e^{-\beta_j t}}{\prod_{i=m,\neq j}^{n} (\beta_i - \beta_j)} \right\} \tag{8}$$

As mentioned previously, this algorithm depended on a predetermined transmutation path in order to properly include every N_m^0 encountered. The methodology employed by CINDER90 starts with a base set of nuclides and follows each path independently. Tests of significance at each step determine when a particular path is stopped, leading to several simplifications:

$$N_m^0 = 0, m \neq 1 \tag{9}$$

$$\bar{Y}_m = 0, m \neq 1 \tag{10}$$

These simplifications lead to the following solution for a given linear sequence:

$$N_n(t) = \prod_{k=1}^{n-1} \gamma_k \left\{ \bar{Y}_1 \left[\frac{1}{\prod_{l=1}^{n} \beta_l} - \sum_{j=1}^{n} \frac{e^{-\beta_j t}}{\prod_{i=1,\neq j}^{n} (\beta_i - \beta_j)} \right] + N_1^0 \sum_{j=1}^{n} \frac{e^{-\beta_j t}}{\prod_{i=1,\neq j}^{n} (\beta_i - \beta_j)} \right\} \tag{11}$$

The test for significance calculates the passby quantity, which is the time-integrated transmutation of that nuclide for the time interval.

$$P_n(t) = \int_0^t N_n(t) \beta_n dt \tag{12}$$

The passby can be interpreted as the progeny of nuclide n resulting from decay or transmutation. If a given nuclide has an extremely low probability of producing progeny in the time interval being investigated, then the transmutation chain will be terminated.

Because CINDER90 is a zero-dimensional code, it must be linked to a steady state reaction rate calculator, MCNP in the case of MCNPX, in order to capture the spatial resolution and spectral change of the time-dependent reaction rate behavior. As isotopes absorb neutrons and undergo numerous nuclear reactions resulting in new isotopes, the neutron energy spectrum will change due to how the neutrons will interact with the newly created nuclides.[45] It is vital that transmutation rates be recalculated when isotope concentration changes result in significant changes in the neutron energy spectrum. This results in dividing an irradiation/depletion calculation into many time steps where a steady state recalculation of reaction rates is completed at defined time intervals. The capture reactions are assumed constant over a specified time step and used in the time-dependent nuclide concentration calculation. The new number densities are then used in subsequent steady-state reaction rate calculations, and the process repeats itself until the final time step is completed.

III.D. Non-Destructive Assay - Gamma Spectroscopy

Although there are many different technologies used for gamma spectroscopy measurements, it is widely accepted in the field that the use of High-Purity Germanium (HPGe) based detectors is the gold standard. Although HPGe based detectors are among the most expensive and require cooling to liquid nitrogen (77 K) temperatures, the gamma energy resolution achievable with an HPGe detector exceeds that of all other technologies. Table 4 shows some of the more common materials used for gamma spectroscopy, and illustrates the difference between these types of detectors. Energy resolution is particularly important when trying to decipher many gamma energy photo-peaks from numerous radioactive nuclides – as is this case in used nuclear fuel measurements presented in this work.

Table 4 Comparison of several detector materials[46]

Material	Atomic Numbers	Energy per e-h pair (eV)	Best Energy Resolution at 122 keV (keV)
Ge (77 K)	32	2.96	0.46
CdTe (300 K)	48, 52	4.43	3.80
HGI_2 (300 K)	80, 53	6.50	3.50
GaAs (300 K)	31, 33	4.2	2.60
NaI (300 K)	11, 53	-	14.2

Like all semiconductor based detectors, HPGe detectors rely on the detection of charge carriers (electrons and holes) that are generated within the detection crystal by the deposition of energy from gamma-ray interactions. Gamma-rays interact primarily through

Compton scattering or the photo-electric effect within the crystal, elevating electrons from the valence band to the conduction band. There is a relatively small probability for pair-production reactions if the gamma-ray energy is more than 1.022 MeV. The relatively small band gap between the conduction band and valence band in germanium (~0.7 eV) is one of the large reasons why it has excellent energy resolution. Once in the conduction band, these electrons (and holes) respond to the electric field applied across the detection crystal and drift to an electrical contact to create the electrical signal that can be amplified and measured.

The first step when using any gamma-ray detector is the calibration – both with respect to energy and efficiency. The energy calibration is extremely straight-forward, and can be done effectively using a standard calibration source with gamma-ray energies that are representative of the energies expected to be measured. An energy calibration can be done using only two gamma-energy photoelectric peaks with known energies and assuming a linear response, but even the best detector systems can show some minor nonlinearity, so it is useful to have multiple calibration peaks at various energies along the energy range of interest to account for these nonlinearities.

Table 5 Multiple gamma-rays emitted in the decay of ^{152}Eu[47]

Energy (keV)	**Yield (%)**	**Uncertainty (%)**
121.78	28.58	0.09
244.70	7.58	0.03
344.28	26.52	0.51
411.12	2.23	0.02
443.97	3.15	0.03
778.89	12.94	0.14
867.37	4.25	0.02
964.08	14.60	0.04
1112.07	13.64	0.04
1408.01	21.00	0.05

The efficiency calibration is slightly more involved, and includes the use of the absolute yields from each gamma-ray listed in Table 5. Equation 13 shows how the efficiencies were calculated for each gamma energy photo peak. The count rate is the total counts in the photo peak found at the listed energy divided by the measurement time, the activity is the radioactivity of the standard in Becquerel (decay corrected from the source manufacture date), and the yield is the absolute yield of the given gamma-ray count per decay, as listed in Table 5.

$$\varepsilon = \frac{Count\ Rate\ (C/s)}{Activity\ (Bq) * Yield} \tag{13}$$

Once all of the efficiencies had been calculated for each gamma-ray photo peak in Table 5, an interpolation fitting function was used to give an estimated efficiency for all energies between the low and high characterized energy from the ^{152}Eu gamma-rays. A commonly used formula was used, a linear function relating the logarithm of the efficiency to the logarithm of the energy, where E_0 is a fixed reference energy and the values of a_i are the fitting parameters.

$$\ln(\varepsilon) = \sum_{i=1}^{N} a_i \left(\ln\left(\frac{E}{E_0}\right) \right)^{i-1} \tag{14}$$

For all of the efficiency calibrations used in this work, N was set to 4 or 5 depending on which value gave the best fit according to the Matlab *polyfit* function, which returned the parameters (a_i's) that gave the best fit (in a least squares sense). Figure 2 illustrates the shape of a standard efficiency curve, as stated by Canberra, one of the largest HPGe detector manufacturing companies.

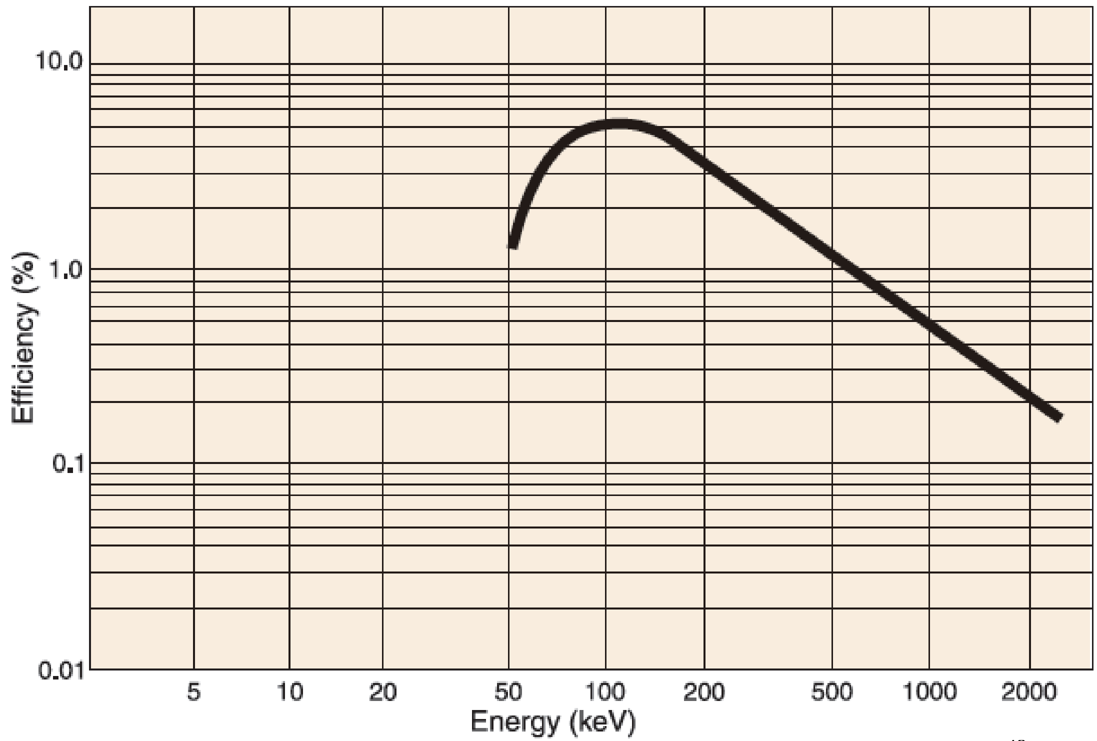


Figure 2: Example efficiency curve for a Canberra germanium detector.[49]

The shape of the curve is related to the photon interaction cross-section vs. energy for the photoelectric effect – which decreases as a function of energy. The efficiency drops at lower energies due to photon's getting absorbed before entering the sensitive volume of the germanium crystal – either getting absorbed in the outer cap, beryllium window, or the contact or "dead layer" of the detection crystal itself. For gamma-rays of about 200 keV or greater, the attenuation is negligible, but can be significant for gamma-rays below 100 keV.[48]

Once the detection system has been calibrated and fully characterized, a gamma spectrum can be measured and analyzed. As an example of the methodology used in this work to estimate the activities of various nuclides within the dissolved neutron-irradiated fuel samples, a common measurement when interrogating any used fuel will be described. One of the most widely accepted and implemented techniques for measuring burnup in irradiated nuclear fuel involves measuring the activity of specific fission-products. The absolute gamma-ray activity of a particular fission-product can serve as a burnup monitor if the following conditions are met[46]:

1) The fission-product should ideally have similar fission yields for the major uranium and plutonium fissioning nuclides. If the yields are substantially different then the effective fission yield could depend significantly on the reactor's operating history and initial fuel composition.
2) The neutron capture cross section of the fission-product should be low enough so that the observed fission-product concentration is due only to fission and not lost by secondary neutron capture.
3) The half-life of the fission-product should be long compared to the irradiation time, so the fission-product does not decay significantly during irradiation.
4) The energy of the gamma-ray used to quantify the fission-product should ideally be of relatively high energy to escape the fuel pin and be above the low-energy background present in the spectrum from the Compton continuum.

If these conditions are met, then the measured gamma-ray activity I (counts/s) from the selected isotope is proportional to the number N of fission-product nuclei formed during irradiation:

$$I = \varepsilon k N \lambda e^{-\lambda T} \tag{15}$$

where I = gamma-ray activity (counts/s)

ε = absolute detector efficiency at that energy

k = branching ratio for the specific gamma of the nuclide

λ = fission-product decay constant

T = cooling time

After solving Equation (15) for N, the atom percent burnup can be calculated from

$$\% \, burnup = \frac{N/Y}{U} * 100 \tag{16}$$

where

Y = effective fission yield

U = number of initial uranium atoms

^{137}Cs is easily the most widely accepted burnup indicator, because its neutron absorption cross sections are negligible, its fission yield from both ^{235}U and ^{239}Pu are very similar, and it has a relatively long half-life of 30.07 years. Using the 662 keV gamma-ray emitted from ^{137}Cs, the measured activity was determined, the branching ratio is known, and the efficiency was measured using the calibration. This was the first activity measured, and was then used to make assumptions about the exposure of the irradiated fuel samples.

A similar method was used to measure other nuclide activities within the used fuel samples, with one of the only differences arising from nuclides that had multiple gamma-rays of different energies to measure. In this case, a standard weighted average was used, with σ^{-2} as the weights, as illustrated in Eq. 17. This results in an average where less precise measurements contribute much less to the final estimate.

$$\bar{x} = \frac{\sum_i^N x_i \sigma_i^{-2}}{\sum_i^N \sigma_i^{-2}} \tag{17}$$

III.E. Destructive Assay – Inductively Coupled Plasma Mass Spectrometry

Inductively Coupled Plasma Mass Spectrometry or ICP-MS is an analytical technique that can be used to determine elemental and isotopic compositions of samples by measuring the mass-to-charge ratio of an ionized sample. Mass spectrometry in general is widely heralded for its high precision (< 1% uncertainty achievable) and sensitivity (~ parts per billion (ppb)). Another key capability of prime importance in this work is that this measurement technique can be used to measure stable nuclides. The drawbacks associated with this technique are usually a high cost and extensive sample preparation time. It is also extremely rare to find a system and operator that are capable of accepting radioactive samples, which is one reason why the measurements were not conducted at Texas A&M. The measurements done as part of this work were accomplished in collaboration with the University of Missouri – using their instrument and operator to complete the measurements of samples sent from the Texas A&M radiochemical laboratory. The measurements done for this work used a NexION 300X ICP-MS single channel machine in standard mode. The results were then shared with Texas A&M and the analysis was conducted jointly. A brief description of the operation of the ICP-MS measurements follows.

Upon arrival of the samples, they are diluted and aspirated into a nebulizer and introduced into the argon plasma as aerosol droplets. The high temperature plasma converts the atoms of the sample into ions, and the ions are subsequently separated and detected by the mass spectrometer. Once the sample atoms are ionized they travel in the argon sample stream into the low pressure region of the mass spectrometer through inverted funnel-like devices called cones. These small cones with a hole in the center serve as the interface between the plasma (at atmospheric pressure) and the filtering quadrupole, which operates at low pressure (<1 x 10^{-5} torr). The cones also ensure that the center of the sample stream is introduced into the mass-spectrometer, but these can become blocked, introducing limits on the total amount of dissolved solids in the sample. This is one of the reasons that necessitates that the samples be diluted prior to being introduced to the system. The ion beam exiting the interface region of the instrument contains non-ionized materials and photons. In the case of the NexION 300X ICP-MS, a quadrupole oriented perpendicular to the beam (called a Quadrupole Ion Deflector or QID) is used to divert the ion beam, thus effectively removing the non-ionized atoms and photons from the beam. The ion beam then travels inside of another quadrupole oriented parallel to the beam that serves as a mass filter. A quadrupole works by setting voltages and radio frequencies to allow ions of a given mass-to-charge ratio to remain stable within the rods and pass through to the detector, whereas other ions are unstable and ejected. Thus, any mass-to-charge ratio can be analyzed with the same detector without the need for any moving parts. The ions that exit the mass filter strike a dynode which releases electrons each time an ion strikes it. A series of dynodes is used to amplify the signal until a measurable pulse is created – which is counted by the software controlling the system.

As with any analytical measurement, a calibration is extremely important for obtaining quantitative results. The measurements conducted as a part of this work were calibrated using a variety of sources to ensure that an accurate system response could be determined for a wide mass range and elemental composition. A calibration measurement consisted of the preparation of a source with a known concentration (ppb) of several elements and the recording of the system response (cps) for the numerous mass values. For example, for a calibration sample containing natural uranium at a concentration of 11.48 ppb, the system response would be calculated as follows:

$$System\ Response\left(\frac{ppb}{cps}\right) = \frac{11.48\,ppb * 0.992745}{CPS\ @\ mass\ 238} \tag{18}$$

This system response could then be used to determine the concentration of ^{238}U in an unknown sample. Care must be taken when using this approach to make sure that there weren't multiple elements contributing to the signal in a single mass bin. This was possible due to the complexity of several of the calibration standards which contained multiple elements with several stable isotopes. Where possible, calibration samples were chosen to avoid this problem, and accounted for when not. Another concern when measuring radioactive isotopes using calibration standards with only stable isotopes is that a system response couldn't be found that matched the mass precisely. In these cases, the closest available mass that matched the species being calculated was used (i.e. using ^{133}Cs calibration source for ^{137}Cs and ^{134}Cs signals).

In order to reduce uncertainty, each measurement of counts for each mass in the sample was the mean calculated from 5 separate scans. One of the primary sources of error for the mass spectroscopic measurements was the drift of the system response. For several of the calibration standards, this response changed from 5% up to 10% from calibration scans conducted prior to the sample measurements to those conducted afterward. These two scans were averaged, and an appropriate uncertainty was utilized given the two response calculations. This, along with background interferences, contributed to a relatively large uncertainty in the mass spectroscopy measurements.

IV. MCNPX SIMULATION OF DUO_2 NEUTRON IRRADIATION*

The first step in the project was accomplished by developing a Monte-Carlo model using MCNPX and CINDER90 to simulate the irradiation of the DUO_2 samples in a fast neutron flux (accomplished in the High Flux Isotope Reactor (HFIR) at ORNL). This step was crucial for three reasons: firstly, to validate the predictive capabilities of the method with experimental results, secondly to compare the irradiation conducted at the HFIR to the hypothetical irradiation of a fast breeder reactor blanket, and finally to serve as a data point for the 'library' used in the final comparison methodology for the source attribution of plutonium. The comparison to experimental results will establish confidence in the method and the simulations, while the comparison between the HFIR and FBR models will establish how representative the physical samples produced through this work are of material that would be recovered from an FBR blanket.

The first step in modeling the experiment conducted in the HFIR at ORNL was to obtain an accurate model of the core. The model that was used was developed by ORNL for reactor cycle 400 and is well documented in their report[50]. The report, published in 2005, documented an effort to get away from direct measurements or expert opinion as sources of data for the reactivity worth and heat generation rate of specimens to be irradiated in the reactor. The document was specifically written to ensure the correct implementation and use of the computational model of the HFIR – making it invaluable to this effort.

---

*Part of the data reported in this chapter is reprinted with permission from "Comparison of FBR and HFIR Monte-Carlo Simulations with Validation from Gamma Spectroscopy in Support of the NFASP Project," by Mathew W. Swinney, published in the Winter 2014 meeting Transactions, Volume 111, November 9-13, 2014 Anaheim, CA, pgs. 999-1001. Copyright 2014 by the American Nuclear Society, La Grange Park, Illinois.

IV.A. HFIR Description

The HFIR has several purposes – primarily as an isotope production and test reactor, with a rated power of 100 MWth (typically operated at 85 MWth). It is a pressurized light-water, flux-trap type reactor that uses Highly Enriched Uranium (HEU) oxide (U_3O_8) as fuel. It has an incredibly high steady-state thermal neutron flux (~2.6×10^{15} n/cm^2 s), which is the primary reason it was chosen for the irradiation for this project. In order to obtain a fast neutron spectrum using a thermal reactor, a gadolinium sheath was used surrounding the irradiation capsule to absorb the thermal neutrons – resulting in only the epithermal/fast neutrons reaching the fuel samples inside the capsule. In a typical research reactor, obtaining the burnup required for this project using the gadolinium sheath would have taken one to two years – whereas the sample reached the burnup required in less than two months in HFIR.

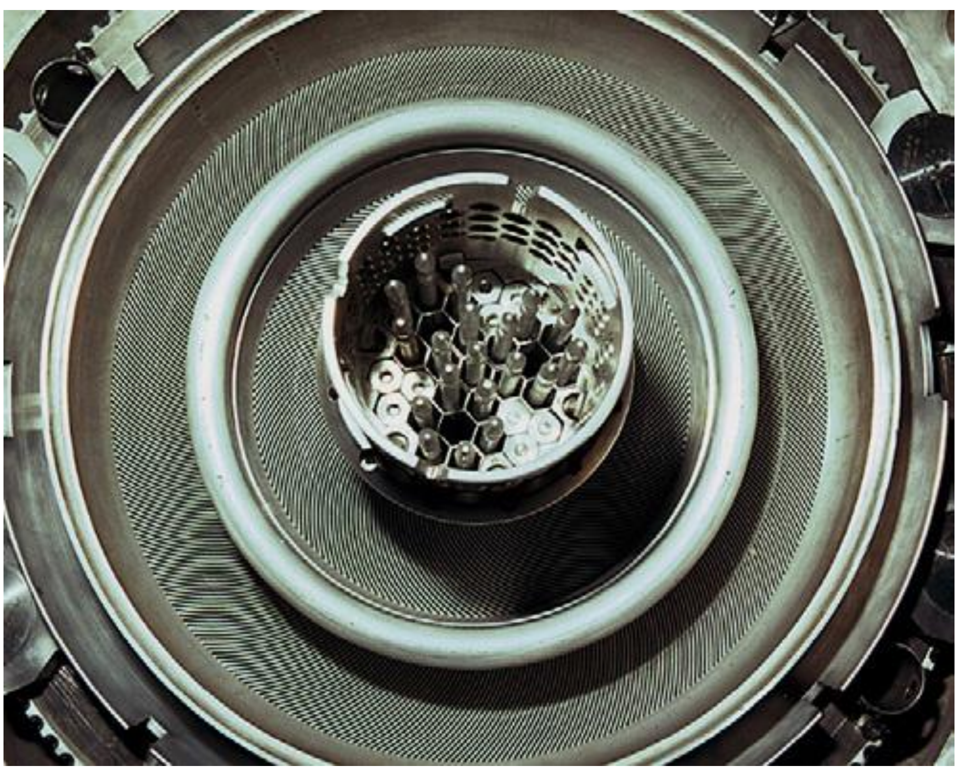


Figure 3: The HFIR core, showing the central flux trap region surrounded by the inner and outer fueled regions.

The reactor core is shown in Fig. 3 with the flux trap used for experimental targets in the center, surrounded by concentric annular regions, each about 60 cm high (active height is 50 cm). The fuel is 9.43 kg of ^{235}U (U_3O_8-aluminum) in the form of 540 (171 inner, 369 outer) involute-shaped aluminum clad fuel plates. Figure 4 shows the original MCNP model created for cycle 400, including the outer beryllium reflector, experimental facilities, and beam tubes. As shown, the fuel was modeled by homogenizing the uranium fuel, aluminum, and water between the plates into 17 radial regions – each representing different effective ^{235}U concentrations in the radial direction of the fuel plate. The model is quoted to predict the multiplication factor to within 1%, using upwards of 60 million particle histories.

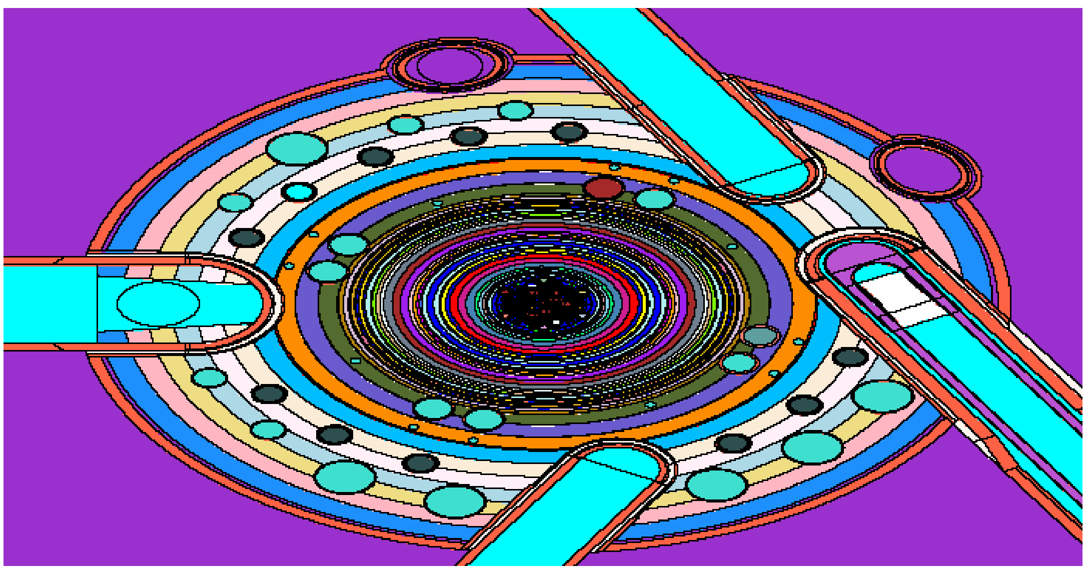


Figure 4: The original MCNP model for HFIR at cycle 400 – a cross section at the horizontal mid-plane (x-y).

IV.B. HFIR Model Modification

Using the HFIR cycle 400 MCNP input file as a starting point, several modifications were then implemented. Firstly, minor changes were made to utilize up-to-date cross-section libraries for some of the materials for which they were available. The initial source definition was also modified to originate neutrons only in the fueled region, which was divided into 7 radial sections; the probability of a source neutron originating in any given section was set to be proportional to the volume of the given section. This was accomplished to improve the source convergence in the first simulations that will not have beginning neutron source files. The code for the source specification can be seen below:

```
kcode  100000 1.0 100 10100
sdef  erg=d1 axs=0 0 1 rad=d2 ext=d3
sp1 -3 0.988 2.249
si2   0  7.140  8.960  10.780  12.600  15.130  16.592  18.054  19.516  20.978
sp2  0  0.092  0.113   0.133   0.000     0.145    0.159   0.172    0.186    0.000
si3   -25 25
sp3  -21 0
```

After these changes were made to the model, the multiplication factor of the simulation created for this project was compared with that reported for the cycle 400 model to insure that there was agreement and no erroneous changes were made. The reported k_{eff} from the model created was 1.00855 ± 0.00013, vs a k_{eff} of 1.00870 ± 0.00013 that was stated in the ORNL report; this results in a statistically insignificant difference of 15 ± 18 pcm.

IV.C. Irradiation Capsule Description

Once the previously discussed - relatively minor changes - were implemented, the experimental samples along with the gadolinium sheath and titanium capsule were modeled and incorporated into the HFIR simulation in the appropriate location. The shielded rabbit capsule utilized a 22.86 mm tall Gd thermal shield (designed to maximize the fast-to-thermal flux ratio) that could contain up to six fuel samples in the form of transmission electron microscopy (TEM) discs (~3 mm in diameter and ~ 0.2 mm thick). This form was used because it could be easily fabricated at ORNL, it fit into the irradiation capsule that had been previously used in the HFIR, and to control the total amount of generated plutonium and dose of the samples. The minimum thickness of the Gd was about 2.275 mm. The fact that the six DUO_2 disks and the Gd shielded rabbit capsule were of an existing design previously approved for irradiation at the HFIR simplified and expedited the irradiation.

The fuel samples were fabricated using commercially available DUO_2 (0.2562 wt% ^{235}U) powder supplied by AREVA – a copy of the isotopic and impurity data supplied with the material can be found in Appendix A. This isotopic data was incorporated in to the MCNP material modeling the irradiation samples, which were assumed to have a density of 95% theoretical density (10.5 g/cc). Table 6 shows the actual disk characterization data provided by ORNL after fabrication of the samples, while Table 7 lists their location within the irradiation capsule.

Table 6 DUO_2 disk characterization data

Specimen	Mass (g)	Diameter (cm)	Thickness (cm)	Density (g/cc)	Density (%Theoretical)
01A	0.0135	0.279	0.0223	9.902	90.35
01B	0.0139	0.281	0.0217	10.329	94.24
03A	0.0144	0.282	0.0228	10.112	92.26
05A	0.0157	0.275	0.026	10.166	92.76
05B	0.0132	0.275	0.0209	10.633	97.02
06A	0.013	0.276	0.0205	10.599	96.71
Average	0.014	0.278	0.224	10.290	93.89

Table 7 Capsule loading details (position 1 is at the bottom)

Vertical Position	Specimen
6	03A
5	05A
4	05B
3	01A
2	01B
1	06A

Each of the six specimens was surrounded by ZrO_2 disks to reduce any interactions between the fuel samples and the gadolinium spacers. A titanium-vanadium alloy rabbit held the gadolinium spacers in place, with a spring inside to secure the samples and to ensure good axial thermal contact directly through all of the gadolinium/ZrO_2/DUO_2 interfaces. Finally, this was placed in a standard aluminum rabbit used in the HFIR flux trap irradiation facilities, as seen in Fig. 5. The mechanical specifications used for both the capsule fabrication and simulation are attached as Appendix B.

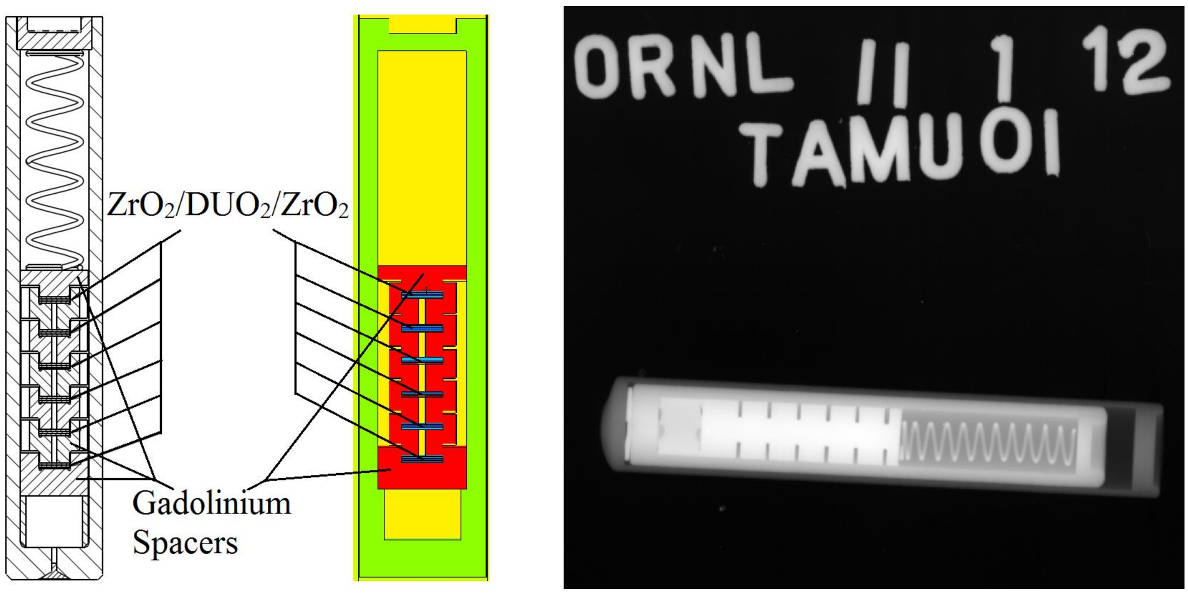


Figure 5: A comparison of the irradiation capsule schematic and MCNP model (left) and a radiograph of the capsule prior to irradiation at ORNL (right).

The HFIR target was placed in position C-5 in vertical location 7 – occupying a position running from approximately 15.6 to 22.1 cm above the reactor mid-plane. Figure 6 illustrates the flux target identification scheme, while Fig. 7 shows a cross-section of the MCNP model to highlight the vertical location of the irradiation capsule.

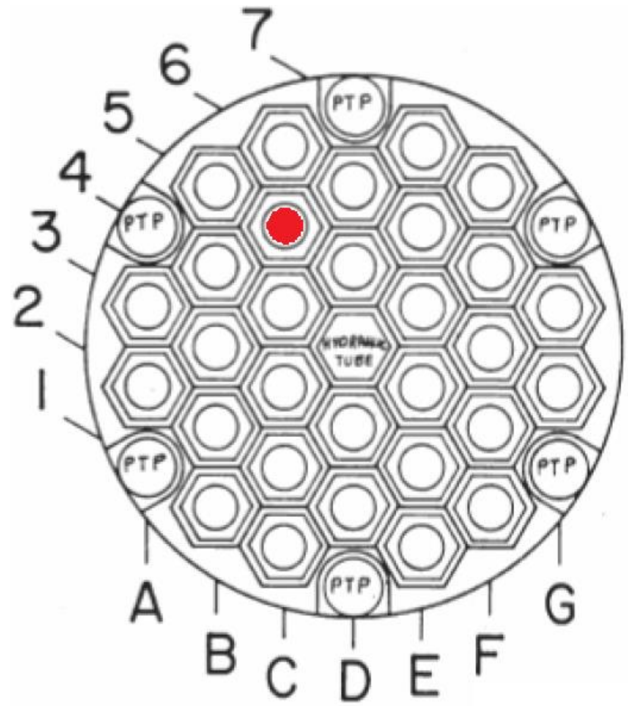


Figure 6: HFIR central flux target position identification scheme with C-5 highlighted.

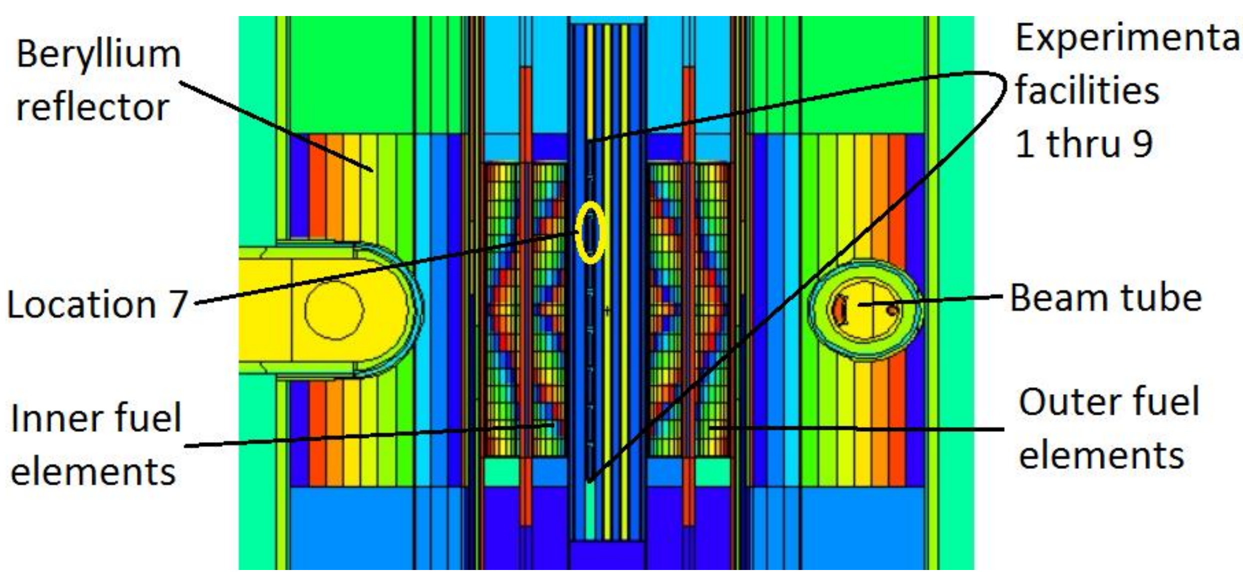


Figure 7: HFIR MCNP model illustrating vertical experimental facilities in the flux trap region, with the irradiation capsule location highlighted.

The only significant omission from the MCNP model is the spring designed to secure the gadolinium and fuel specimens inside the capsule. This omission is due to the relative complexity of modeling the geometry of the spring and justified by the relatively small impact the steel spring is expected to have on the neutron field to which the DUO_2 samples were irradiated in. Other than this omission, the experimental holder was modeled as accurately as possible given the schematics made available by ORNL pertaining to the sample holder.

IV.D. Monte-Carlo Particle Determination

In any Monte-Carlo radiation transport simulation for reactor core physics calculations, appropriate selection of simulation parameters such as the number of neutrons starting per generation and number of generations to be simulated should be made to achieve the required precision in the predictions. This is especially true in the presented simulation because of the relatively small volume of space that is of interest – the DUO_2 TEM disks. A particle scoping study was conducted primarily focusing on the 238 group neutron flux inside the six DUO_2 disks. The energy group structure used in this simulation was identical to that used in the SCALE code package developed by ORNL.[51] To ensure that this flux was well characterized, the goal was set to keep the ratio of the standard deviation to the predicted value (relative error) of the neutron flux for the energy groups of interest (10 keV to 2 MeV) to be less than 0.1 (<10%).

Initial runs were completed with 1, 10, and 100 million histories, but these were found to be too inaccurate. At one billion particles, the average relative standard deviation of the neutron flux in the samples in the energy range of concern (10 keV to 2 MeV) was less than 0.07. Table 8 illustrates several iterations of the simulation that were run to optimize the number of particles per cycle (PPC) and the total number of cycles. The statistics for one of the runs with one million particles is also shown for comparison. Notice that even with a billion particles, there were some energy bins with a relative error greater than 0.1, but the vast majority of these were in the thermal part of the spectrum where there is very little flux due to the absorption of the gadolinium spacers. Ultimately, the configuration that used 100,000 particles per cycle with 10,000 cycles was selected because it had the highest figure-of-merit, an acceptable average relative error, and the shortest run time. The run time was of prime concern, because the MCNPX simulations are computer intensive. The run time for the final simulation including 10 depletion steps was over 40 days running in parallel on a 32 core, 2.7 GHz, 64 GB RAM desktop workstation.

Table 8 Particle Statistics for HFIR MCNP Simulation

					Energy Bins w/ stdev > 0.1		10 keV - 2 MeV
PPC	**Cycles**	**Version**	**FOM**	**Run Time (min.)**	**10 keV to 2 MeV**	**Total**	**Average Stdev.**
100000	10000	1	1.9	21247	5	127	0.0664
20000	50000	2	1.8	25451	5	134	0.0642
200000	5000	3	1.9	22607	5	125	0.0651
1000000	1000	4	1.8	23695	5	124	0.0647
31623	31622	5	1.8	24414	5	126	0.0667
50000	20000	6	1.8	26911	5	129	0.0643
20000	5000	-	1.8	2564	42	191	0.1988

IV.E. CINDER90 Burnup Parameters

The final step in modeling the irradiation of the DUO_2 fuel samples in the flux trap facility in the HFIR was to determine the burnup parameters. Table 9 contains the irradiation details provided by ORNL, which equates to approximately 50.23 Effective Full-Power Days

(EFPDs) at the rated power of 85 MWth. These were split into two nearly equal cycles, with a 94 day down-time period separating the irradiation periods.

Table 9 HFIR operating information for the irradiation of the DUO2 samples

HFIR Cycle	**Start Time**	**End Time**	**MW days**
446	1/8/2013 08:22	2/2/2013 07:49	2125.94
447	5/7/2013 06:17	6/1/2013 12:51	2143.58

In the MCNPX model created, the BURN card was implemented to deplete the irradiated material – including the DUO_2 samples, the ZrO_2 disks, and the gadolinium surrounding both. A total of ten times steps were used to limit errors associated with the changing fuel composition, and to capture the build-up of important short lived fission-products, like I-135, which decays to the neutron absorber Xe-135 with a half-life of 6.7 hours. The input parameters used for the burnup can be seen below:

```
BURN        TIME =   0.3 0.7 12 12 94 0.3 0.7 12 12 506
            PFRAC =  1   1   1  1  0   1   1   1  1   0
            POWER = 85
```

The 94 day, no power time step represents the scheduled outage between cycles 446 and 447, whereas the final 506 day decay step represents the time between the final irradiation day and the gamma spectroscopy measurements performed at Texas A&M. The final simulation used for the comparison used an additional 0.7 day burn step before the final decay step, for reasons that will be explained in the next chapter. This final simulation resulted in a full burn of 50.7 EFPD at 85 MWt (or 4310 MWd), compared to the 50.23 EFPD (or 4270 MWd) reported by ORNL – a difference of less than 1%. A copy of the entire MCNPX deck is attached as Appendix C.

IV.F. Simulation Results

The first piece of data that was generated from the simulation discussed above was the multiplication factor, $k_{eff.}$ As mentioned previously, the k_{eff} of the HFIR simulation was 1.00855 ± 0.00013; this matches very closely with the cycle 400 multiplication factor, 1.00870 ± 0.00013. This comparison was simply used as a check to ensure that the model was performing as expected, and that no gross errors were made in re-creating the original HFIR MCNP model.

The next set of data generated from this investigation was the 238 group neutron flux calculated by MCNPX in the DUO_2 samples contained in the special irradiation capsule located at the C-5 location (flux trap location) of the HFIR.

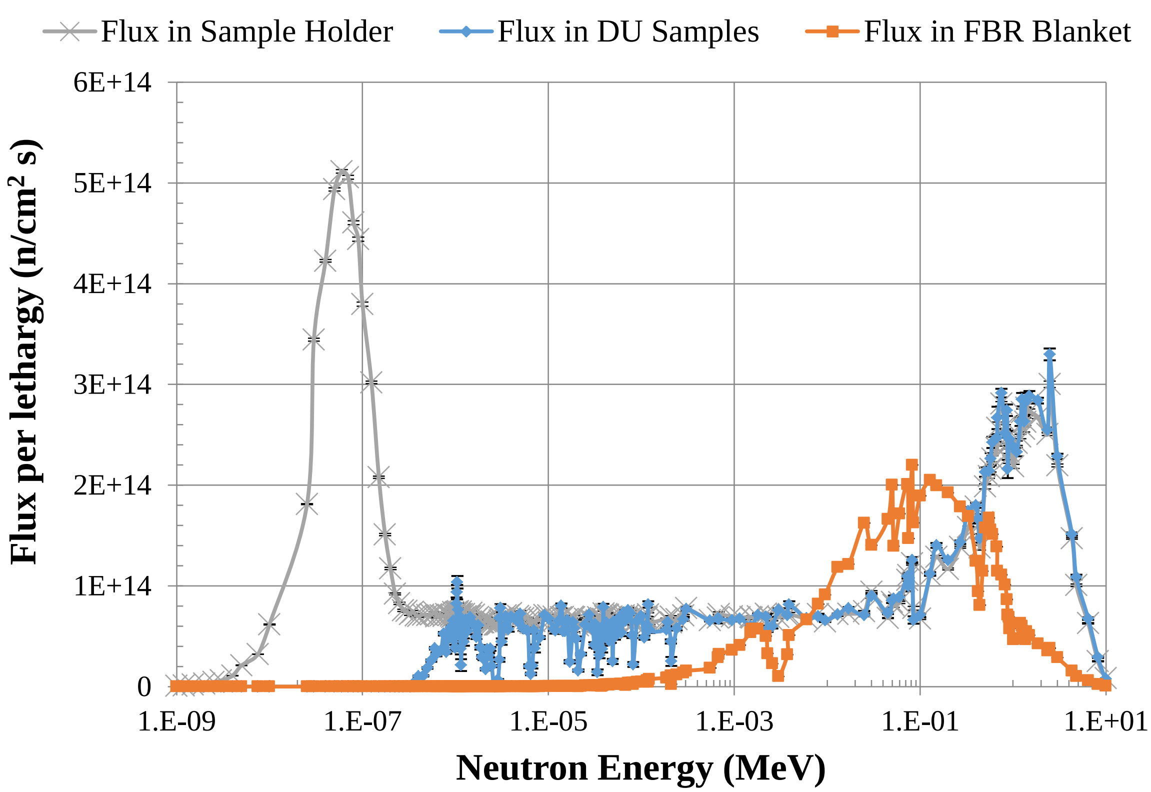


Figure 8: A comparison of the flux in the sample holder and in the fuel samples illustrating the enhancement of the fast/thermal ratio inside the capsule achieved using the Gd sheath.

Figure 8 compares the neutron flux in the DUO_2 samples to that outside the gadolinium capsule, illustrating the effectiveness of the gadolinium in eliminating the thermal neutron flux by a very large fraction from the neutron spectrum 'seen' by the DUO_2 samples. The 238 energy group neutron fluxes presented in Fig. 8 were calculated using the F4 tally feature in MCNPX, which calculated the neutron group fluxes averaged over all six DUO_2 samples. The F4 tally is a standard track length flux estimate (n-cm/cm^{3}s) measured in a cell – in this case, the cell consisted of a six-part cell representing all six fuel samples. The next step was to compare the neutron flux experienced by the DUO_2 samples in HFIR to the flux that is experienced by the DUO_2 in the blanket of an FBR. The FBR core used for the comparison shown was modeled and investigated for the blanket material (DUO_2) neutron irradiation characteristics by the study that preceded this work[52].

Another comparison of the 238 energy group neutron fluxes calculated in the FBR blanket material and inside the HFIR irradiation capsule is shown in Fig. 9. It can be seen from Fig. 9 that even though the majority of the thermal neutron flux was absorbed by the gadolinium sheath for the HFIR capsule case, there was still a substantial component of the neutron flux in the 'intermediate' energies (>.625 eV & <0.1 keV). The ^{238}U radiative capture cross-section is also displayed, which will be useful to illustrate the difference quantitatively; the HFIR neutron flux will result in approximately 68% more radiative capture reactions in ^{238}U producing ^{239}Pu when compared to the FBR neutron flux. The ^{238}U cross-section plot also helps to explain much of the resonance structure found within both the HFIR and FBR neutron spectra.

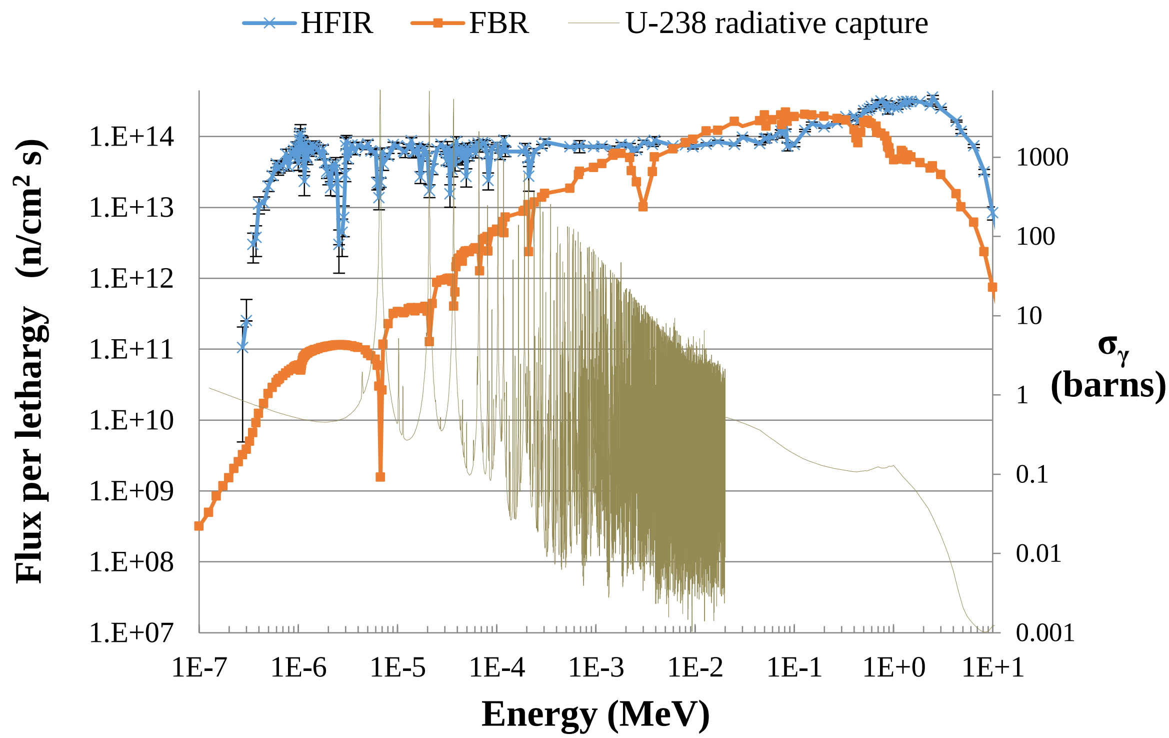


Figure 9: This figure illustrates the comparison of the neutron flux in the DUO_2 samples in the HFIR simulation to the neutron flux in the radial blanket DUO_2 material of the FBR simulation.

Although the ^{238}U capture cross-section explains much of the structure seen in each spectrum, there are artifacts unique to both spectra. For example, the resonance structure at low energies apparent in the HFIR spectrum, but not in the FBR spectrum, is due to the gadolinium surrounding the fuel samples – which would obviously not be present in the FBR spectrum. Similarly, the large resonance absorption at approximately 3 keV in the FBR spectrum, that is not present in the HFIR spectrum, represents the large ^{23}Na (sodium is used as coolant in FBRs) resonance absorption (n,γ) at this energy.

The next set of results involves another metric for comparing the neutron flux in the HFIR simulation to the simulation of the FBR; the fast-to-thermal ratio. The fast-to-thermal ratio is defined here as the percentage of the neutron flux above 0.1 MeV divided by the percentage below 0.5 eV. This ratio serves as a simple but quantitative way to illustrate how 'thermal' or 'fast' a particular spectrum is. The fast-to-thermal ratio is shown in Table 10 for the blanket region of the FBR simulation, the HFIR sample holder, and the HFIR fuel samples. As previously mentioned, the ratio is about 186 for the DUO_2 fuel samples, but is on the order of 50,000 for a typical FBR. Although this is significantly different, the ratio is also presented for the sample holder in the HFIR simulation; 0.73. So the fast-to-thermal ratio within the Gd sheath is over two orders of magnitude closer to the FBR ratio than a typical thermal neutron environment.

Table 10 Comparison of the Fast-to-Thermal Ratio of the MCNPX Simulations

Simulation Tally	Flux < 0.5 eV (n/cm^2 s)	Flux > 0.1 MeV (n/cm^2 s)	Fast-to-Thermal Ratio
FBR	8.70E+09	4.09E+14	50580
HFIR (Holder)	1.13E+15	8.28E+14	0.73
HFIR (Sample)	4.71E+12	8.77E+14	186

The final set of simulation results that can be used to illustrate how the HFIR fuel samples compare to the FBR blanket material involves the direct comparison of the fission-product concentrations. Table 11 shows the results for five isotopes of interest at specific burnups and normalized to the total amount of plutonium. Unfortunately, there were no simulation burnup steps that matched exactly, so the results were taken for two steps that matched as close as possible (1.5 vs. 1.3 GWD/MTU). As expected, the ^{137}Cs concentration is 15% higher in the HFIR simulation, because this isotope was used to calculate the burnup value, and the burnup in the HFIR simulation (at this step) was 15% higher than the FBR step. Taking this known source of discrepancy into account, most of the isotopic concentrations agree fairly well, excluding perhaps ^{134}Cs. Once again, the HFIR results match much more closely with the FBR concentrations than the PHWR values.[39]

Table 11 Comparison of the fission-product concentrations of the MCNPX simulations

Isotope	HFIR (g/gPu) (~1.5 GWD/MTU)	FBR (g/gPu) (~1.3 GWD/MTU)	HFIR/FBR
^{144}Ce	2.75E-03	1.98E-03	1.39
^{134}Cs	9.39E-05	4.96E-05	1.89
^{137}Cs	4.70E-03	4.10E-03	1.15
^{154}Eu	2.19E-05	1.64E-05	1.34
^{125}Sb	6.09E-05	4.83E-05	1.26

Ultimately, although the HFIR model exhibits noteworthy differences from the FBR model in neutron flux shape, fast-to-thermal ratio, and fission-product concentrations, it appears that the fuel samples irradiated in the gadolinium emulate fuel in the blanket of an FBR much more so than fuel in a typical thermal neutron reactor. Furthermore, the differences are expected due to the manner in which the investigators manufactured the fast neutron spectrum for the irradiation. The HFIR simulation will still be useful in validating the modeling methodology when compared to the experimental measurements and the actual irradiation samples should still be representative of fuel irradiated in a fast neutron environment. The fission-product concentrations predicted by the MCNPX simulation will be presented in the following chapter, where they will be compared to both the gamma and mass spectroscopic measurements.

IV.G. Other Simulation Considerations

Although the MCNPX model was created with as much detail as possible, and the neutron flux spectra shape matched well with what was reported from ORNL, there were some early indications that the simulation was incomplete. The initial gamma spectroscopy measurements (discussed in the next chapter) predicted a significantly higher burnup than the initial MCNPX model was predicting - approximately 4.57 GWd/MTU vs. 3.29 GWd/MTU. Both of which were significantly higher than the requested burnup of ~1 GWd/MTU. This prompted some questions about possible mistakes in the model, or other sources that could explain this discrepancy.

Most of the discrepancy between the burnup that was requested by Texas A&M and the burnup of the samples that were received was eventually attributed to human error. During the creation of the MCNP model that was used to predict the burnup of the samples by ORNL personnel, a simple mistake was made in the location of the fuel samples. The locations of the irradiated fuel samples in the original simulation designed by ORNL were from 19.51 to 20.48 cm from the mid-plane of the HFIR, whereas the actual locations of the samples were from 17.06 to 18.69 cm. The difference between the position of the lowest sample in the ORNL simulation and the actual lowest sample was approximately 2.45 cm. Although this may seem like a small difference, this resulted in a significantly lower flux prediction than that which the samples were exposed to and thereby under-predicted the final burnup. In the HFIR, relatively small errors in the height of the samples can have a large influence on the final burnup of the fuel samples.

Once the discrepancy with respect to the sample location between the Texas A&M and ORNL models was resolved, an investigation to resolve the discrepancy between the model and the preliminary gamma spectroscopy measurements was conducted. The first explanation originated from the fact that there was incomplete knowledge about which of the six fuel sample samples was measured. The ORNL report[53] documented some considerable difficulty that was encountered during the extraction of the fuel samples that resulted in the loss of much of the material. During the extraction of the DUO_2 disks from the gadolinium holders, several of the disks were broken and some were lost. Ultimately, only one whole DUO_2 disk was retrieved successfully, and any information on where the retrieved disk was axially within the stack was lost. In response to this, another F4 track-length flux tally was performed to investigate the difference in flux across the irradiation rabbit, highlighting the difference of the flux at each of the six fuel sample locations. As seen in Figure 10, the neutron flux increased about 5.65% from the center of the irradiation capsule to the bottom, a distance of only 0.805 cm. If the sample that was retrieved successfully and measured was from the bottom of the stack, it would have a corresponding increase in the burnup relative to the 'average' initially calculated. Upon further review, the mass of the measured DUO_2 pellet received by Texas A&M was 12.9 mg, which matches most closely with sample 06A listed in Table 6 – which was in fact at the bottom of the irradiation capsule. In light of this information, the final simulation 'shifted' the entire irradiation capsule down 0.805 cm in order to get an average burnup more representative of the bottom most fuel sample. This relatively small change in the model resulted in an increase in the predicted burnup from 3.29 GWd/MTU to 3.56 GWd/MTU. Although this predicted burnup more closely matched the burnup predicted (4.57 GWd/MTU), it was apparent that there still was a very large discrepancy between the simulation prediction and the burnup estimated via gamma spectroscopy.

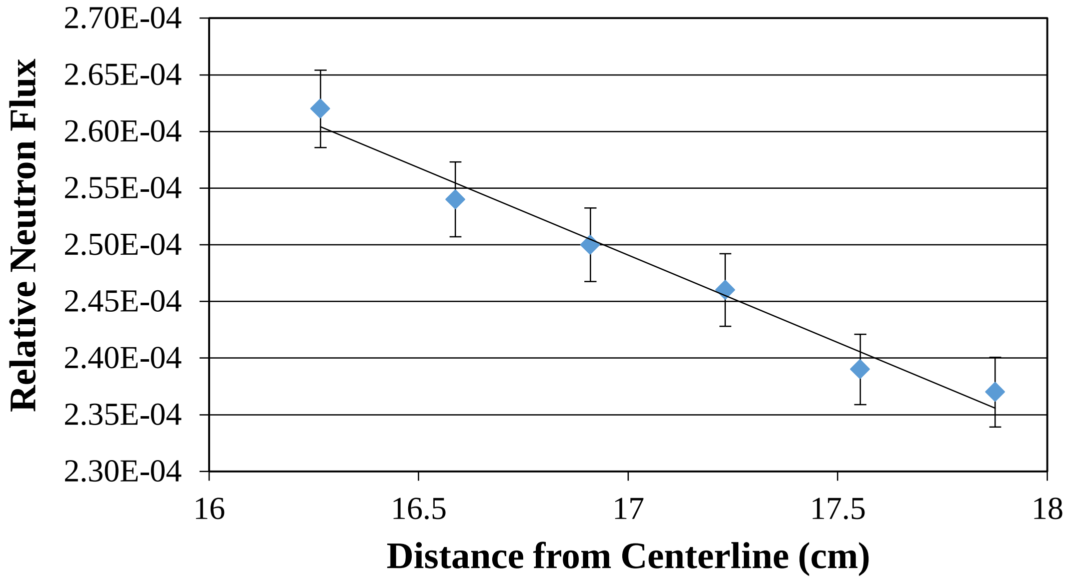


Figure 10: A plot of the neutron flux across the irradiation rabbit – with data points at each fuel sample location, illustrating a ~6% increase across the capsule.

Although the use of the 'shifted' fuel samples rectified about 20% of the discrepancy in burnup, there was still a significant difference between the burnup predicted by the MCNPX model and that predicted by the gamma spectroscopy measurements. This led to an investigation to determine how sensitive the burnup of the sample was to minor changes in the power of the irradiation (or equivalently, the length or EFPD). With any reactor, the measurement of power has some error to it – although the HFIR is very well characterized – it was thought that this error was certainly less than 5% and more likely less than 1%. Figure 11 illustrates the ^{137}Cs concentration in the fuel samples as a function of irradiation time as calculated in the MCNPX model.

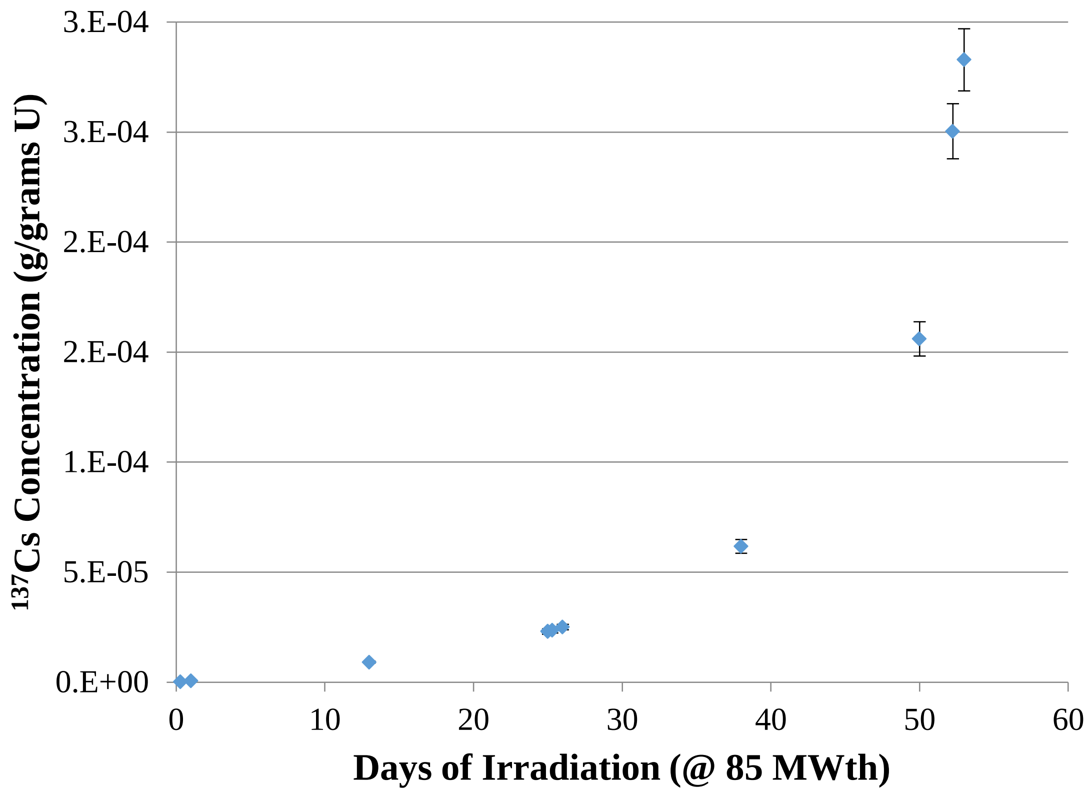


Figure 11: A plot of the amount of ^{137}Cs vs. the days of irradiation in the HFIR, illustrating the non-linear burnup as a function of time.

Due to the nature of the fuel samples, the burnup of the samples did not increase linearly vs. time. Because the vast majority of the burnup was coming from the fissioning of plutonium, there was little fissioning in the sample at the beginning of the irradiation. However, once the plutonium began to build up, the burnup of the sample increased more and more (parabolic vs linear). This meant that small changes in the irradiation time (or power) led to large changes in burnup, as illustrated in Fig. 11. Figure 12 illustrates the plutonium buildup and percentage of the plutonium that is ^{239}Pu as a function of burnup in the DUO_2 fuel samples. The burnup units are arbitrary, but are taken from the ^{137}Cs values, whereas the total plutonium is the total for all of the simulated fuel samples.

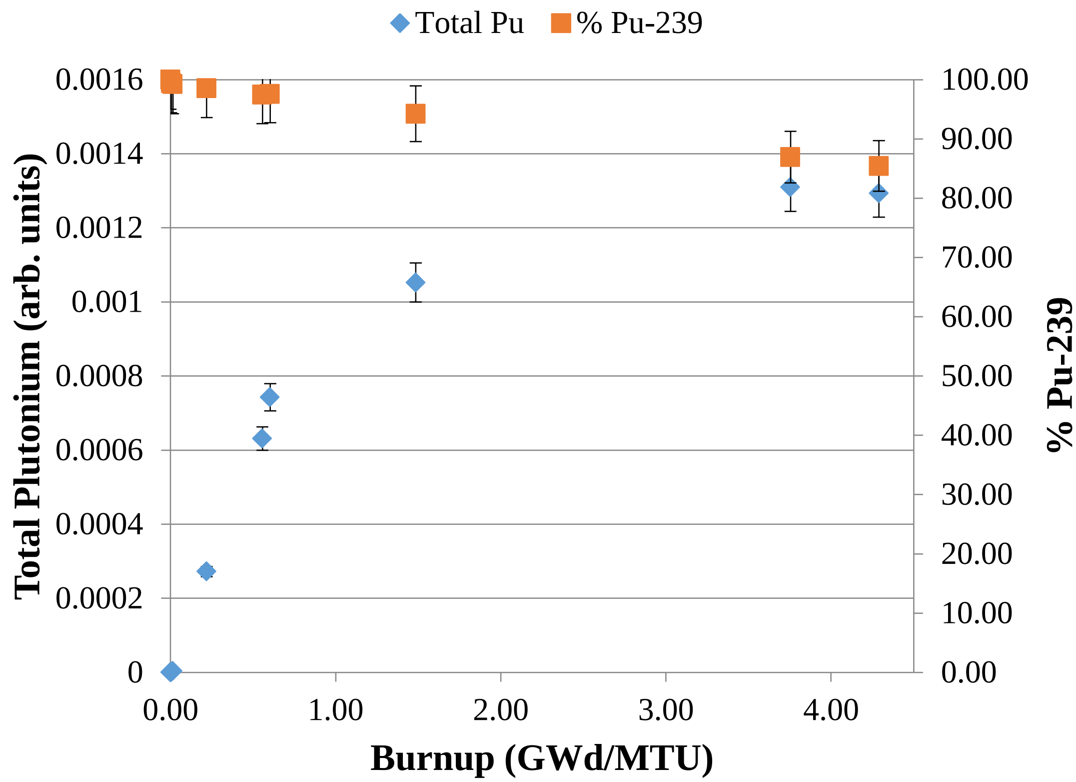


Figure 12: Plots of the plutonium buildup and composition vs. burnup in the fuel samples irradiated in the HFIR.

The final simulation added 0.7 days to the initial 50 day irradiation (a 1.4% increase), which subsequently lead to a ~20% increase in burnup. This was chosen primarily to match with the gamma spectroscopic measurements, but also matched to within less than 1% of the EFPDs reported by ORNL. As shown in Table 9, the stated total energy output in MW days was 4270 from the ORNL report vs. 4310 MW days with the final 50.7 day MCNPX simulation. This results in a 0.93% difference between the EFPD reported and the simulation – which is likely on the order of the uncertainty of the measurement conducted by ORNL to determine the power of the reactor. Table 12 presents all of the predicted burnups for the different iterations of the MCNPX model; it also includes the initial ORNL prediction and the gamma spectroscopy burnup estimate.

Table 12 Burnup predictions for various simulation iterations

Iteration	Burnup Prediction Method Description	Predicted Burnup (GWd/MTU)
1	**ORNL Prediction**	1.34
2	**Initial TAMU Simulation**	3.29
3	**2 with pellets shifted down 0.805 cm**	3.56
4	**3 with additional 0.7 days of irradiation**	4.29
	Gamma Spectroscopy Measurement	4.57

After the ‘shifting’ of the irradiation capsule down and the small increase to the EFPD of the simulation, the predicted concentrations matched up extremely well with the gamma spectroscopy and the mass spectroscopy measurements – results that will be presented in the next chapter.

Finally, with any modeling or simulation work, there will be simplifications, imperfect information, and uncertainty that could contribute to modeling error; some possible sources of error that could be present in this work will now be discussed. One of the expected inconsistencies between the model and the actual reactor include the target loading – the experiments modeled in the cycle 400 MCNP model included several aluminum dummies as well as other experiments that weren’t present for the cycle 446 and 447 irradiations. These experiments would likely have had a relatively minor influence on the neutron flux observed at the target location, but this effect would not be captured in this simulation. Unfortunately, obtaining information about every single experiment in the flux trap during these two irradiation cycles was not within the scope of this work – and it is believed, would not have had a significant effect on the results.

Another simplification used in this modeling work was the fact that the fuel wasn’t burned and control elements weren’t moved. Although in a typical reactor this would have a relatively large effect on the magnitude of the neutron flux, the HFIR was designed to maintain a constant flux within the flux trap in the center of the reactor, hence any changes in the neutron flux due to fuel burnup were considered insignificant. The primary reason for this simplification is the savings in the computing cost – had the simulation required a flux tally at every fuel location in order to do a depletion calculation, the computing time would have increased substantially. The increase in fidelity was not worth the increase in computing time – a sentiment that was echoed by the ORNL personnel collaborating on this work.

Other possible sources of error include the homogenization of the fueled regions in the model and the fact that there is uncertainty with respect to the cross section data used for the neutron transport calculation within MCNPX 2.7 (ENDF/B-6). These last two sources of error are likely the smallest contributors to the overall modeling error, and would take efforts outside the scope of this work to resolve.

V. EXPERIMENTAL PROCEDURE AND RESULTS

Because the primary objective of this work was to characterize a physical sample that would be representative of the blanket material (DUO_2) irradiated in an FBR, the next step was to obtain DUO_2 fuel samples irradiated to a low burnup (less than 5 GWd/MTU) in a fast neutron environment. Due to the lack of a readily available fast neutron spectrum reactor that the investigators could take samples from, an alternative approach had to be invented. As previously mentioned, the experiment involved irradiating DUO_2 samples in the HFIR at ORNL by placing the fuel samples inside a specially designed neutron irradiation capsule surrounded with a gadolinium sheath. Even though the HFIR is a thermal neutron reactor, the irradiation of DUO_2 pellets in a fast neutron environment could be facilitated by employing the special neutron irradiation capsule.

Six DUO_2 disks were fabricated at ORNL with an average mass of 0.014 ± 7.12% grams, a thickness of 0.0224 ± 8.82 % cm, an average diameter of 0.278 ± 1.11 % cm, and an average density of 10.29 ± 2.79 % g/cm^3. Figure 13 provides an illustration of a representative capsule with a full complement of diagnostic elements. The flux wires and SiC thermometry were not included in the irradiation, in an effort to minimize the cost of the irradiation; therefore each of the six specimen locations was filled with a $ZrO_2/DUO_2/ZrO_2$ disk stack. The ZrO_2 disks were placed above and below the fuel specimens to avoid material interactions with the gadolinium spacers. The gadolinium stack was housed in a titanium alloy inner can, which was placed in a standard aluminum rabbit designed for holding experiments inside the HFIR flux trap region.

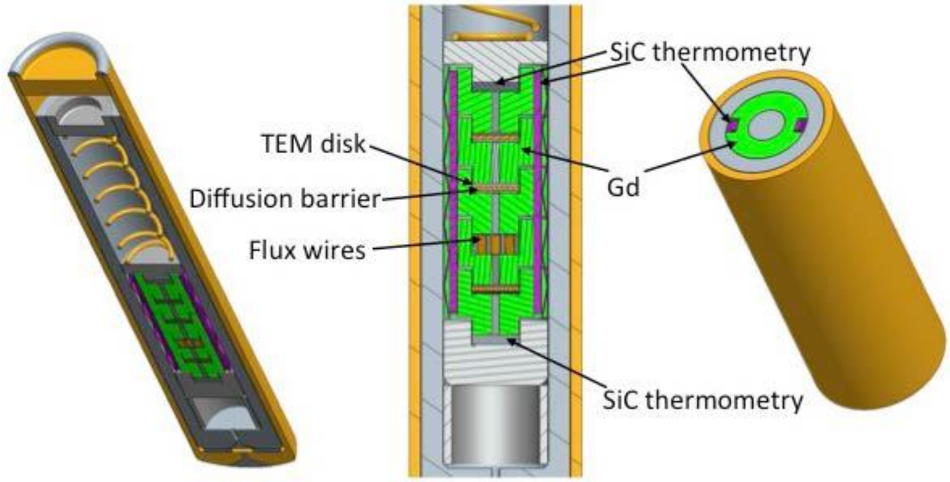


Figure 13: The experimental rabbit irradiation facility used in the HFIR irradiation. Flux wires and SiC thermometry were not used in the irradiation, so all six specimen locations housed DUO_2 fuel samples.

The target locations in HFIR provided a thermal neutron flux (< 0.5 eV) in the range of 1.2 x 10^{15} to 2.5 x 10^{15} n-cm^{-2} s^{-1} and a fast neutron flux (>0.10 MeV) in the range of 5.1 x 10^{14} to 1.2 x 10^{15} n-cm^{-2} s^{-1}. As shown in the previous chapter, the gadolinium sheath provides a fast-to-thermal ratio of about ~200. Upon removal from the HFIR, the rabbit capsule was allowed to cool in the HFIR pool from June 1, 2013 prior to the shipment of the samples to Texas A&M University. Due to various complications at ORNL during the extraction of the DUO_2 samples from the irradiation capsule, only one whole disk and several disk fragments (~1.85 equivalent disks) were recovered and eventually received at Texas A&M University (on August 31, 2013). After the rabbit was removed from the HFIR core and allowed to cool in a HFIR pool storage rack it was shipped to the Irradiated Materials Examination and Testing Hot Cell Facility at ORNL where the capsule was disassembled. The test specimens were extracted, photographed, packaged for shipment, and shipped to Texas A&M University.

In order to validate the results of the fission-product and actinide concentrations in the DUO_2 samples obtained from the MCNPX burnup simulations, gamma spectroscopy was the first analytical technique used to measure the samples in order to compare the results with the predicted isotope concentrations.[54] One of the most important pieces of information regarding the irradiation was the burnup; if the ^{137}Cs activity of the sample could be accurately characterized via gamma spectroscopy, then this would be a relatively simple but reliable data point to confirm or discredit the accuracy of the MCNPX simulation.

V.A. Preliminary Gamma Spectroscopic Measurements

After being received at the Nuclear Science Center (NSC) at Texas A&M on August 31, 2013, the irradiated DUO_2 fuel samples were allowed to decay for approximately eight months prior to dissolution. This dissolution was necessary to reduce the overall exposure with those working with the samples during subsequent chemistry and precise gamma spectroscopy measurements. During this time six 'stand-off' preliminary gamma spectroscopic measurements were conducted at the NSC from December 17, 2013 to April 21, 2014. These were conducted in a room in the basement of the NSC, near where the samples were being kept – the heat exchanger room. These measurements were conducted using a portable, mechanically cooled HPGe detector – a Canberra Falcon 5000, as seen in Figure 14.

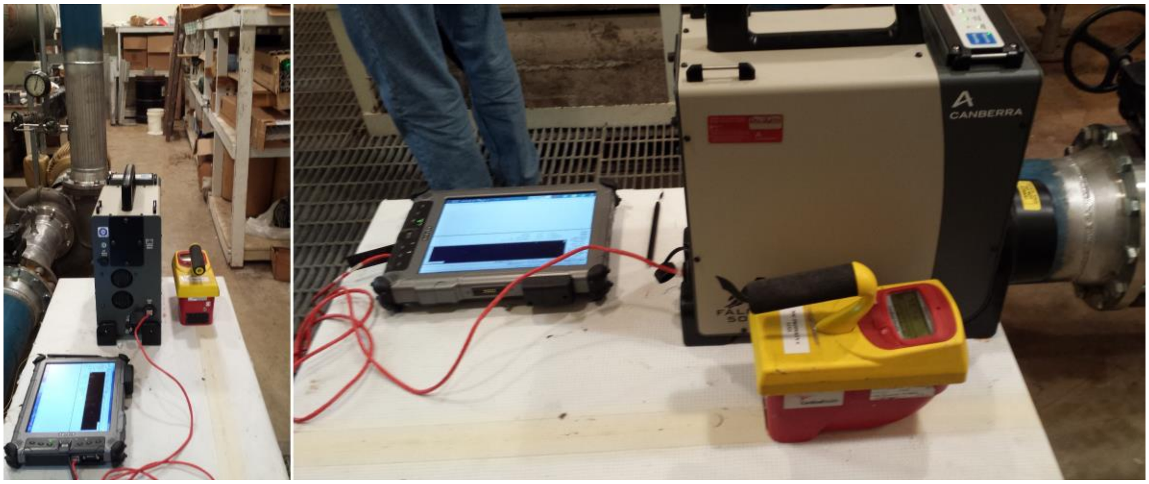


Figure 14: The preliminary gamma spectroscopy measurement setup with the Canberra Falcon 5000 portable HPGe detector.

The experimental setup was very ad-hoc, but was serviceable given the straightforward measurement technique, and ultimately proved to be very useful. By measuring a known ^{137}Cs source at the same position as the fuel sample, a very simple calculation can be done to predict the activity of this one nuclide in the sample, as seen in Eq. 19. By taking the ratio of the two background-subtracted count-rates (CR) and multiplying it by the activity of the known calibration source, the activity of ^{137}Cs in the sample could be calculated. Because the radioactive nuclide being measured in the calibration source and the sample was the same, no energy or efficiency calibration nor a branching ratio needed to be accounted for.

$$A_{Sample} = \frac{A_{Cal.Source} * CR_{Sample}}{CR_{Cal.Source}} \tag{19}$$

The measurement was repeated several times using various calibration sources and with the irradiated DUO_2 sample at different distances from the detector. The conditions of each measurement are given in Table 13, and the results for each measurement are given in Table 14. The calibration activities were decay corrected for the date of the measurement, and the count rates were calculated using the continuum-subtracted count rates reported by the Genie 2000 software provided by Canberra for use with the Falcon 5000. As expected, there was a high level of uncertainty with all of the measurements, but the average of all six measurements yielded a predicted ^{137}Cs activity of 0.183 ± 0.017 mCi that the investigators felt reasonably confident in.

Table 13 Preliminary ^{137}Cs calibration source descriptions

Measurement	Distance (ft)	Source Description	Calibration Source
1	4	NUEN Button Source	.01 mCi @ 8/1/2011
2	4	Nuclear Science Center Source	.08 mCi @ 3/15/1994
3	6	NUEN Button Source	.01 mCi @ 8/1/2011
4	6	Nuclear Science Center Source	.08 mCi @ 3/15/1994
5	24	Texas A&M Cyclotron Source	100 mCi @ 1/1/1964
6	24	NUEN Button Source	.01 mCi @ 8/1/2011

Table 14 Preliminary ^{137}Cs measurements

Measurement	Calibration Activity (mCi)	Calibration Source (cps)	Pellet Measurement (cps)	Pellet Acitivity (mCi)	Error
1	9.391E-03	6.05E+00	1.17E+02	0.181	0.018
2	5.039E-03	2.91E+00	1.17E+02	0.202	0.021
3	9.391E-03	2.64E+00	5.39E+01	0.192	0.020
4	5.039E-03	1.39E+00	5.39E+01	0.196	0.022
5	3.179E+01	6.70E+02	3.20E+00	0.152	0.016
6	9.428E-03	1.67E-01	3.07E+00	0.174	0.019

This preliminary measurement did not agree with the ^{137}Cs activity predicted by the first iteration of the MCNPX simulation, which was 0.134 mCi. Even with the relatively large uncertainty of the measurement, it was clear that there was a statistically significant difference between the prediction and the measurement – which is what prompted the re-designs of the simulation model discussed in the previous chapter. After modifying the simulation to predict the nuclide concentration of the bottom-most fuel sample and increase the EFPDs of the HFIR model by ~1%, the simulation predicted an activity of 0.172 mCi – which is in much better agreement with this preliminary ^{137}Cs measurement. The difference between the final simulation prediction and the preliminary ^{137}Cs measurement was 0.011 ± 0.018 mCi (assuming a 5% uncertainty on the MCNPX value). This preliminary measurement brought attention to the fact that the DUO_2 fuel samples achieved a higher burnup than requested by Texas A&M (1 GWd/MTU) to ORNL, and was the first indication that the MCNPX simulation of the HFIR was not completely representative of the actual irradiation. The burnup predicted via gamma spectroscopy was 4.57 GWd/MTU, whereas the final MCNPX simulation predicted a burnup of 4.29 GWd/MTU – a difference of only 6%. This was determined to be adequate agreement, and served as the first validation of the simulation with experimental data.

V.B. Pellet Dissolution

As mentioned previously, after the fuel samples were received at the NSC at Texas A&M on August 31, 2013, they were allowed to decay for approximately eight months to reduce the exposure of the personnel performing the dissolution. After this time, the samples were transferred to an isolated glovebox at the NSC on May 2, 2014. The only intact DUO_2 disk shipped to Texas A&M was removed from the aluminum container housing the sample and weighed in a weighing boat on an electronic balance. The DUO_2 fuel sample weighed 12.9 ± 0.05 mg; a picture of the measurement can be seen as Fig. 15.

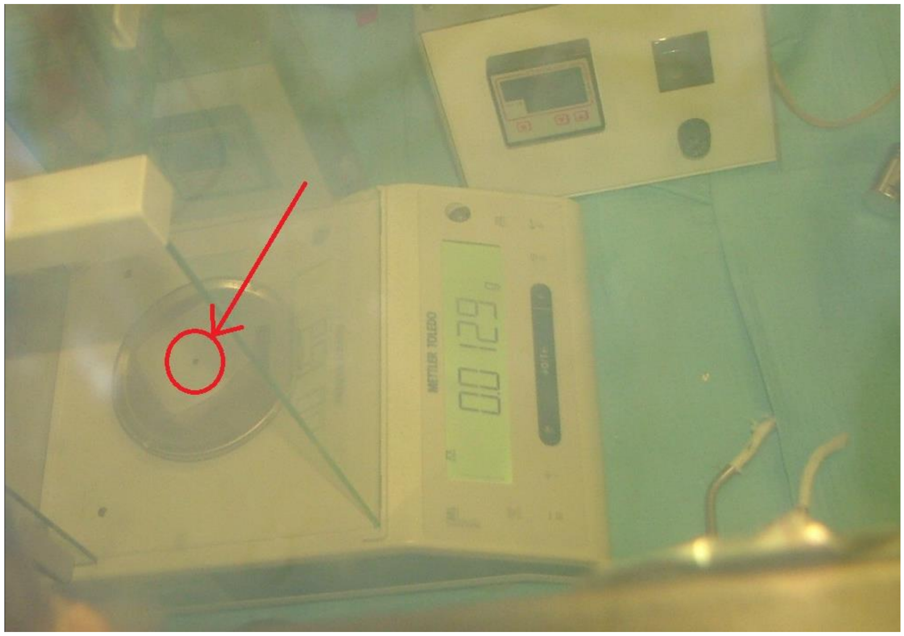


Figure 15: The weighing of the DUO_2 fuel sample inside the NSC glovebox.

The irradiated pellet was then transferred to a round bottom flask, where ~5 ml of 8 M HNO_3 was added and heated to 50 °C with a constant 100 rpm stirring for two hours. The round bottom flask was connected to a cold trap with the help of a schlenk line. The experimental setup for the dissolution of the DUO_2 samples is illustrated in Fig. 16. The fission-product gases such as H_2, CO_2, Kr, Br, I and N_2O were captured in the cold trap inside the molecular sieves which were surrounded by liquid nitrogen. After complete dissolution, the 5.167 ml concentrated 8 M HNO_3 solution was transferred from the round bottom flask to a 20 ml glass scintillation vial. This entire solution was moved to the AGN reactor store room in the Zachry Engineering Building at Texas A&M and kept heavily shielded. From this original solution, 500 µL was taken and diluted to 5 ml 4M HNO_3. This diluted solution, containing ~9.7% of the original pellet, was transferred to the radiochemistry laboratory in the Nuclear Engineering department at Texas A&M University, and would serve as the "stock solution" from which all subsequent samples would be taken.

The dissolution work was performed by Dr. Tarun Bhardwaj of our group in coordination with Dr. Folden and Dr. Chirayath at Texas A&M.

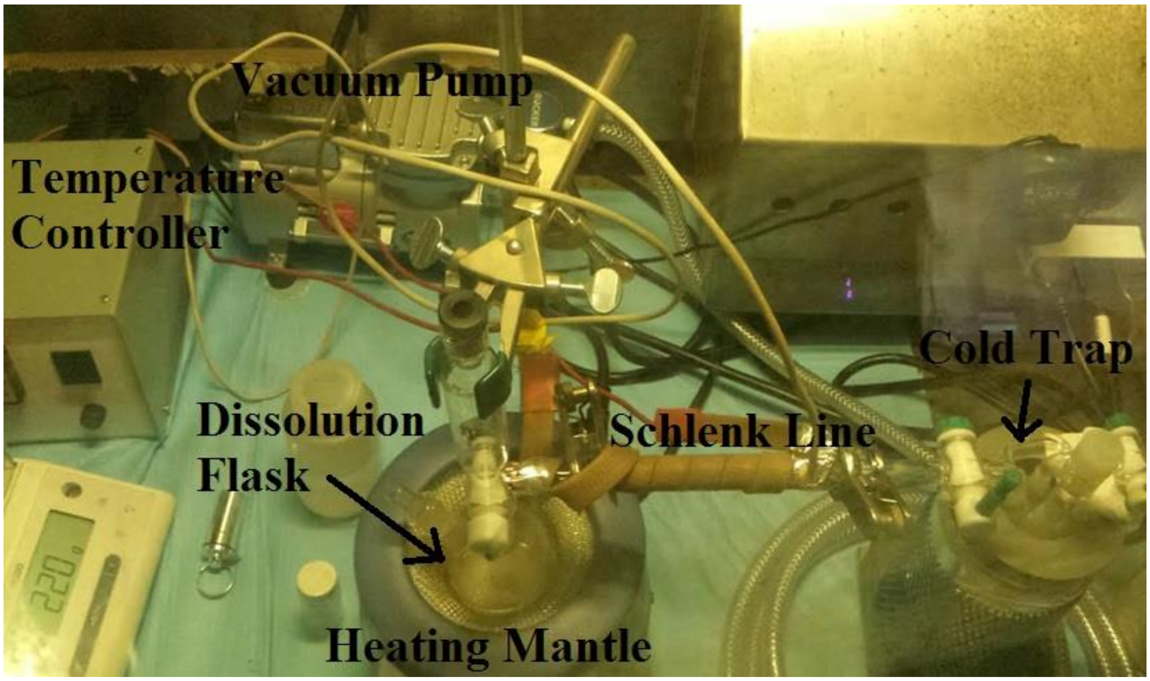


Figure 16: Dissolution apparatus for the DUO_2 pellet at the NSC.

V.C. Gamma Spectroscopy Measurements

Once the solution arrived at the radiochemical laboratory within the Nuclear Engineering department, 500 µL of the stock solution (containing 0.97 % of the sample pellet) was taken and measured with a HPGe detector. The measurements for this part of the work were conducted using a Canberra Model GC4018 High-Purity Germanium (HPGe) detector surrounded by a lead cave designed to minimize background. The gamma spectroscopy measurement setup is shown in Fig. 17, demonstrating how the vial containing a portion of the dissolved DUO_2 sample was placed in a custom built plastic holder mounted on the head of the Canberra HPGe detector at a distance of approximately four inches. At this distance, the dead time in the detector was approximately 15%. Table 15 lists some of the specifications and settings of the detector system. Another layer of lead bricks was placed over the shown cave prior to all of the measurements in order to give 4π sr shielding.

Figure 17: Gamma spectroscopy measurement setup with sample, plastic sample holder, and Canberra Model GC4018 HPGe inside a lead cave.

Table 15 Gamma measurement specifications/settings

HPGe Model:	Canberra GC4018
Serial #:	10210
Bias:	+3500 Volts
Channels:	8192
Energy Range:	0 to 1.5 MeV
Rise Time:	8.8 μs
Flat Top:	1.2 μs
Cryostat Model:	7905-305L
Pre-Amp Model:	2002CSL

Before each gamma measurement, both background and calibration measurements were conducted. A liquid ^{152}Eu source with an activity of 433 nCi (497±0.5 nCi on

2/15/2012) was used to do both the energy and efficiency calibrations for the system. The calibration source was placed in the same vial and plastic holder as the samples to ensure the location was representative of the samples during the measurement. As discussed in the Chapter 3, the europium source emits numerous gamma-rays from 121.8 keV to 1408 keV that can be used to calculate an efficiency curve assuming a form typical of HPGe co-axial detectors. An efficiency curve calculated for this work is shown in Fig. 18, with the interpolation curve created in Matlab displayed.

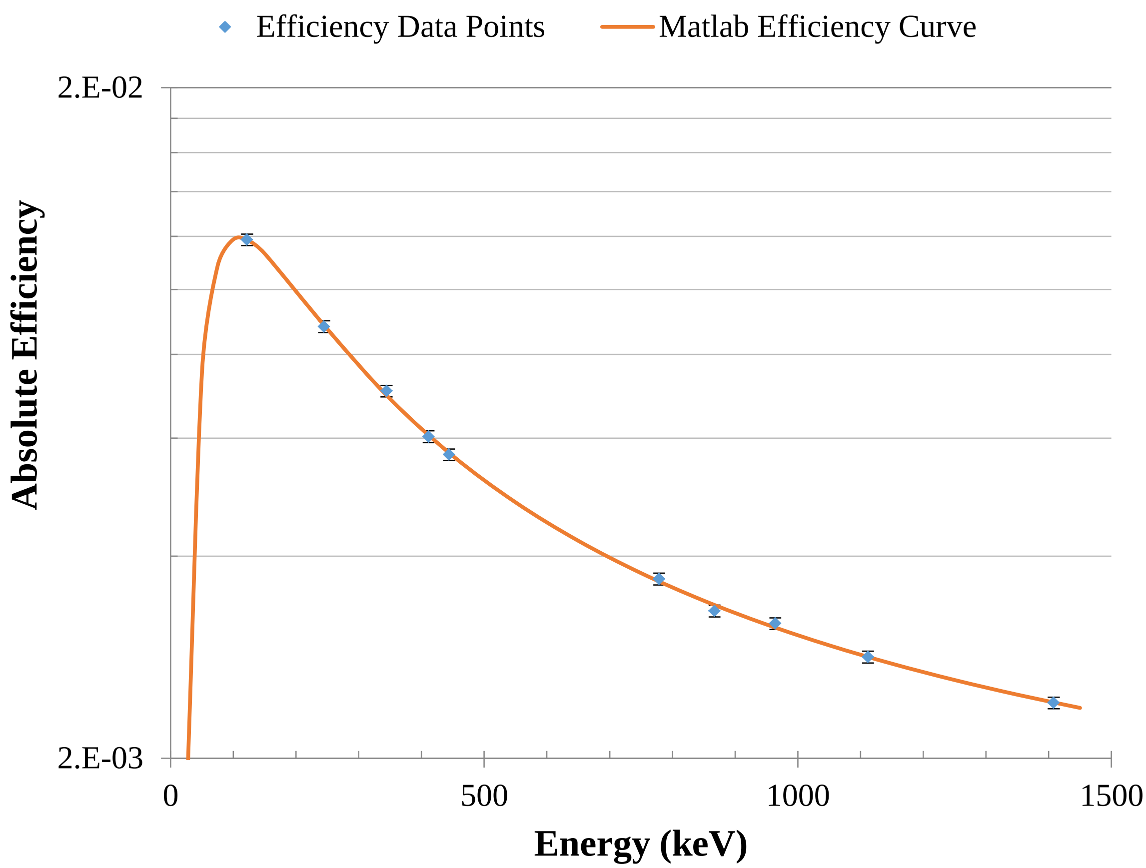


Figure 18: Example of the efficiency curve fitted to a ^{152}Eu calibration measurement that was used to interpolate the energy efficiency for gamma spectroscopic measurements.

The final measured activity of several nuclides of interest were calculated using Eq. 20 and the efficiency, ε, calculated from the curve displayed in Fig. 18:

$$A_n = \frac{C_n}{T * \varepsilon_\gamma * \gamma_n} \tag{20}$$

where: A_n = the activity of nuclide n

C_n = counts in full-energy peak of gamma-ray from nuclide n

T = count time of measurement

ε_γ = detector efficiency at energy of gamma-ray

γ_n = branching ratio, or yield, of the gamma-ray for nuclide n

The nuclides that were measured with this technique are listed in Table 16, including the gamma-emitting nuclides that were predicted to be able to yield information about the neutron environment. There are also a couple of other fission-products that contributed significantly to the overall gamma yield. These were calculated to serve as another check for the simulation results, as well as to ensure that all of the major features in the gamma energy spectrum were attributed. The activities calculated from each gamma-ray were weight-averaged according to the uncertainty from each activity estimate to give the best possible average for the measured activity of each nuclide. The nuclides in parentheses in Table 16 are nuclides that are in secular equilibrium with the parent nuclide and can be used to predict the activity of the parent with high precision. The gamma-ray emissions presented were chosen because they had energies at which an accurate efficiency calculation could be calculated (between 122 keV and 1408 keV), were free of significant interferences (a problem in irradiated fuel measurements), and had large gamma yields with reliable nuclear data. Figure 19 illustrates one of the spectra obtained using the Canberra GC4018 HPGe detector. This spectrum was taken prior to the changes to energy range and number of channels.

Table 16 Gamma lines used to determine activities of specific nuclides

Nuclide	Gamma-ray Energy (keV)
^{144}Ce	133.5, 696.5 (^{144}Pr)
^{125}Sb	427.9, 636
^{134}Cs	563.2, 569.3, 604.7, 795.9, 1365.2
^{137}Cs	661.7
^{154}Eu	1004.7, 1274.4
^{106}Ru (^{106}Rh)	511.9, 621.9, 1050.4, 1128.1
^{95}Zr	724.2, 756.2

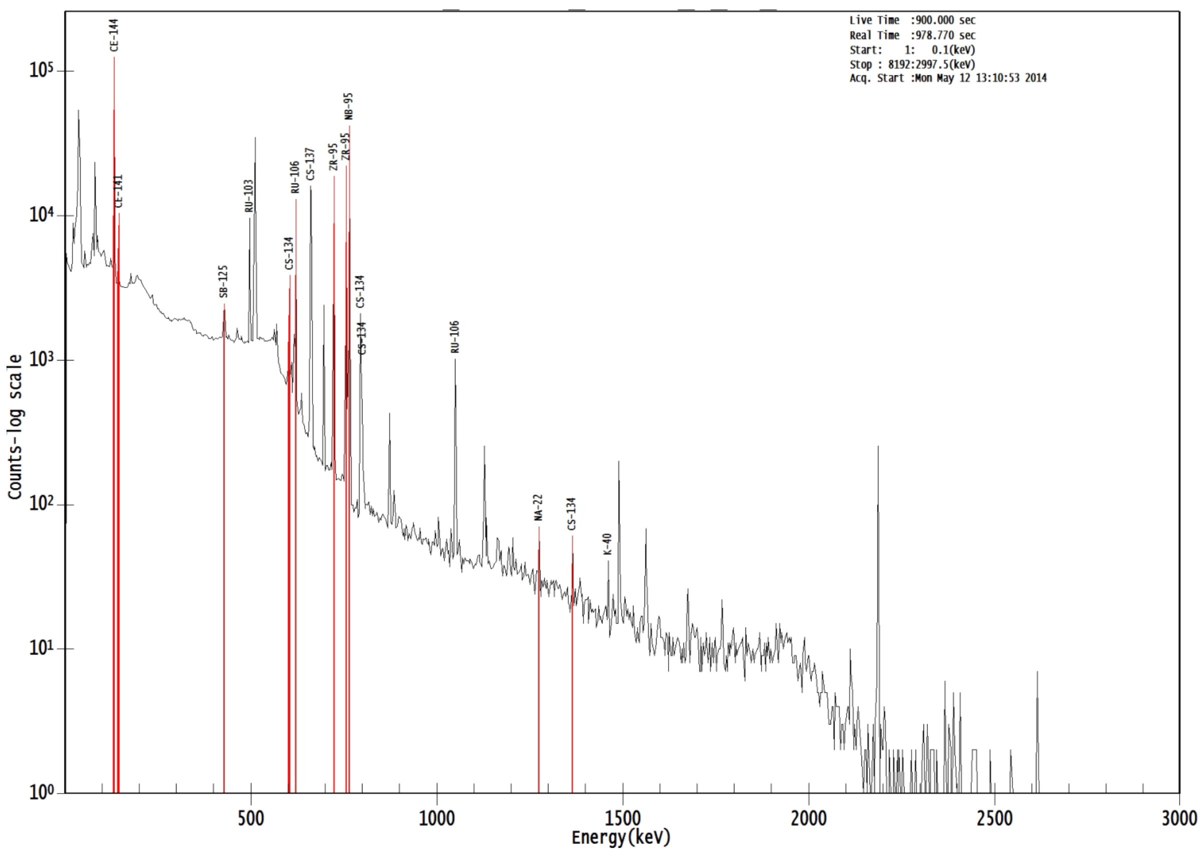


Figure 19: An example of the gamma spectrum from the DUO2 disks.

One of the primary goals of the gamma spectroscopy measurements was to establish confidence in the fission-product estimates in the DUO_2 samples obtained through burnup simulations of the HFIR core using the MCNPX model. To accomplish this, the measured radioactivity of seven isotopes (^{134}Cs, ^{137}Cs, ^{144}Ce, ^{125}Sb, ^{106}Ru, ^{95}Zr, and ^{154}Eu) was compared to the MCNPX results. Table 17 illustrates the results of the measurements for these isotopes. For the ^{137}Cs (662 keV) and ^{125}Sb (428 keV) measurements, only a single gamma photo-peak obtained from the HPGe spectroscopy was used, whereas for the ^{144}Ce (134 keV and 697 keV from ^{144}Pr), ^{106}Ru (512, 622, 1051, 1128, 1195 keV), ^{134}Cs (563, 569, 605, 796, 1365 keV), ^{95}Zr (724, 757 keV) and ^{154}Eu (1005, 1275 keV) measurements, several of the expected gamma-ray peaks were used. The table lists the energies where the peaks were found, the net area and error, the intensity of the given gamma for the isotope (branching ratio), the measured efficiency (from the ^{152}Eu calibration source), and the radioactivity calculated from the measurements. For the nuclides with multiple gamma-ray energy peaks, the activity from each peak was calculated and an average was calculated based on a weighting inversely proportional to the variance for the activity calculated from the given gamma line. The activity was also normalized to the mass of the sample in the measured solution (.129 g), so this is a radioactivity per gram of DUO_2. The values for the reference energies and intensities listed were taken from the Korea Atomic Energy Research Institute website (KAERI 2014).[47]

Table 17 Measured data for activities of selected isotopes

Nuclide	Measured Energy (keV)	Gamma Yield (%)	Net Area	Efficiency (%)	Activity In Solution (Ci/gm)	Final Measured Activity (Ci/gm)	Uncertainty in Final Activity (Ci/gm)
^{144}Ce	133.6	11.09	2154196	1.18	9.07E-02		
(^{144}Pr)	696.6	1.34	89490	0.40	9.20E-02	**9.13E-02**	3.E-03
^{134}Cs	563.4	8.35	14058	0.47	1.96E-03		
	569.5	15.38	25997	0.47	1.98E-03		
	604.9	97.62	155414	0.45	1.96E-03		
	796.0	85.53	115867	0.36	2.07E-03		
	1365.4	3.01	2893	0.25	2.12E-03	**2.01E-03**	4.E-05
^{137}Cs	661.8	85.10	942580	0.42	1.47E-02	**1.47E-02**	4.E-04
^{154}Eu	1004.9	17.91	1756	0.30	1.78E-04		
	1274.7	35.00	2721	0.26	1.65E-04	**1.70E-04**	7.E-06
^{106}Rh	512.0	20.40	1338839	0.51	7.06E-02		
	622.2	9.93	552523	0.44	7.01E-02		
	1050.6	1.56	55791	0.29	6.71E-02		
	1128.2	0.40	13955	0.28	6.80E-02	**6.90E-02**	2.E-03
^{125}Sb	428.1	29.80	40633	0.59	1.27E-03	**1.27E-03**	4.E-05
^{95}Zr	724.3	44.17	150120	0.39	4.83E-03		
	756.9	54.46	177609	0.37	4.80E-03	**4.82E-03**	1.E-04

The activities measured by gamma spectroscopy from five separate measurements of a single vial (~0.97% of the pellet) are displayed in Table 18. These were conducted to ensure that the measurement results were reproducible and reliable, as well as to characterize the error associated with the measurement setup and procedure. Other errors include uncertainties in the activity of the calibration source, errors associated with the curve used to interpolate the detector efficiency, and uncertainties in the nuclear data (branching ratios, decay constants, etc.).

Table 18 Weighted average activity calculation from five gamma spectroscopic measurements

	Activity (Bq)	**Activity (Bq)**	**Activity (Bq)**	**Activity (Bq)**	**Activity (Bq)**	**Weighted Average Activity (Bq)**	**Uncertainty (%)**
Date	**10/17 2014**	**10/18 2014**	**10/20 2014**	**10/21 2014**	**10/22 2014**		
^{144}Ce	4.42E+05	4.50E+05	4.42E+05	4.39E+05	4.42E+05		
	4.41E+05	4.44E+05	4.50E+05	4.42E+05	4.43E+05	**443588**	**2.38**
^{125}Sb	5.49E+03	5.72E+03	5.65E+03	5.59E+03	5.47E+03		
	4.83E+03	5.01E+03	5.18E+03	4.81E+03	4.80E+03	**5357**	**3.99**
^{106}Ru	3.35E+05	3.40E+05	3.46E+05	3.36E+05	3.38E+05		
	3.29E+05	3.32E+05	3.37E+05	3.31E+05	3.32E+05		
	3.20E+05	3.20E+05	3.17E+05	3.16E+05	3.18E+05		
	3.31E+05	3.28E+05	3.27E+05	3.19E+05	3.27E+05		
	3.22E+05	3.19E+05	3.31E+05	3.02E+05	3.22E+05	**327767**	**4.14**
^{134}Cs	8.59E+03	8.73E+03	9.35E+03	9.09E+03	9.11E+03		
	9.02E+03	9.18E+03	9.55E+03	9.35E+03	8.81E+03		
	8.81E+03	8.90E+03	9.06E+03	8.89E+03	8.93E+03		
	9.32E+03	9.39E+03	9.47E+03	9.38E+03	9.47E+03		
	9.71E+03	9.82E+03	9.88E+03	9.83E+03	9.57E+03	**9262**	**2.61**
^{137}Cs	6.40E+04	6.48E+04	6.59E+04	6.49E+04	6.52E+04	**64955**	**1.65**
^{95}Zr	3.06E+04	3.07E+04	3.05E+04	2.97E+04	2.96E+04		
	3.06E+04	3.05E+04	3.03E+04	2.95E+04	2.95E+04	**30149**	**3.00**
^{95}Nb	6.21E+04	6.19E+04	6.15E+04	6.00E+04	6.00E+04	**61086**	**2.01**
^{154}Eu	8.73E+02	8.81E+02	8.35E+02	8.03E+02	8.59E+02		
	8.55E+02	7.97E+02	7.45E+02	8.02E+02	8.30E+02	**831**	**6.24**

The final step in this part of the investigation was to compare the quantities of the various fission-products predicted from the MCNPX simulation to that measured using gamma spectroscopy. Both the simulated and measured values were normalized to the mass of DUO_2 in order to account for differences in the simulated mass and the mass of the actual sample. As can be seen in Table 19, the difference between the simulation and measurement for most of the isotopes is equal to or less than 12%; however, the activity predicted for ^{125}Sb was over 50% larger than the activity that was measured. Upon further investigation, it was discovered that ^{125}Sb is a particularly troublesome nuclide to track using MCNPX. This was supported by the fact that the mass spectroscopy measurements for this isotope agreed with the gamma measurements. Discussions with personnel at ORNL also indicated that ^{125}Sb is a poorly predicted isotope.[55] One of the reasons given for this was that this isotope has multiple production pathways that are inadequately sampled during the burnup simulation method used by MCNPX. Aside from this outlier, the measurements agree reasonably well (within the order of the uncertainty) with the simulation and lend some confidence to the MCNPX models.

Additional uncertainty not mentioned before with respect to the gamma spectroscopy measurements include uncertainties in the weighing of the DUO_2 samples, and uncertainties in the volumes pipetted from the original dissolved solution and the 'stock' solution to create the vial that was actually measured (~1% of the pellet).

Table 19 Comparison of gamma spectroscopy measurements to simulation

	Activity (Bq)	Activity ($Ci/gmDUO_2$)	Uncertainty ($Ci/gmDUO_2$)	Simulation Activity ($Ci/gmDUO_2$)	S/E	Uncertainty (~10% from Sim. Results)
^{144}Ce	443588	9.60E-02	2.29E-03	8.43E-02	**0.88**	0.09
^{124}Cs	9262	2.01E-03	5.24E-05	2.21E-03	**1.10**	0.11
^{137}Cs	64955	1.41E-02	2.32E-04	1.32E-02	**0.94**	0.10
^{154}Eu	831	1.80E-04	1.12E-05	2.00E-04	**1.11**	0.13
^{95}Nb	61086	1.32E-02	2.66E-04	1.31E-02	**0.99**	0.10
^{125}Sb	5357	1.16E-03	4.63E-05	1.75E-03	**1.51**	0.16
^{95}Zr	30149	6.53E-03	1.96E-04	6.00E-03	**0.92**	0.10

Although the gamma spectroscopy measurements were relatively straight-forward, there were some other possible sources of error in the measurements taken with the HPGe detector. For example, there could have been some unknown interferences in the spectrum that could have caused the predicted activities to be high. One possibility for an interference with the ^{137}Cs measurement could have been ^{241}Am (emits a gamma at 662.4); although the impact of this is likely very low due to the low intensity of this gamma, and the relatively miniscule amount of ^{241}Am that should be in the sample. The possibility of this kind of interference with most of the other isotopes is fairly unlikely due to the fact that several gamma lines were used and averaged – if there was this kind of interference, it should be obvious from inconsistencies between the multiple gamma lines. Another source of error could have been in the efficiency calculation. Although ^{152}Eu has many gamma lines that span the energies of concern (200 keV – 1400 keV), none of them lined up exactly with the gamma's from the isotopes in question. This required interpolation to generate an efficiency curve that could be used for the other lines. The interpolated function used matched well

(~3%) with all of the gamma lines from the ^{152}Eu calibration source, so it is unlikely that this error would introduce large errors in the predicted activities.

V.D. Mass Spectroscopy Measurements

After the fuel samples were dissolved, several 50 µL samples were sent off to the University of Missouri for mass spectroscopy measurements. There, on February 25, 2015, Inductively Coupled Plasma Mass Spectrometry (ICP-MS) measurements were taken of the dissolved DUO_2 samples by Dr. James McKamey with a PerkinElmer NexION 300X quadrupole ICP-MS.

Upon receiving the samples, the vials were placed in a centrifuge to drive all of the solution to the bottom of the vials, which resulted in the loss of some of the volumes of many of the samples sent. However, since the mass spectroscopy measurements look at concentrations (in ppb), this was not overly concerning – aside from the fact that the centrifuge was contaminated. After this centrifuging, the samples were carefully weighed and diluted in preparation for insertion in to the ICP-MS. All of the samples that were sent were measured five times, and the count data was averaged across all of the measurements.

After all of the measurements were finished, Dr. McKamey sent a report giving concentration estimates for the actinides, along with raw count data for all of the other mass bins. In order to analyze the data for the other isotopes, the system response had to be determined as described in chapter 3, using the various calibration count data that was sent along with the sample data. The mass spectroscopy results displayed in Table 20 represent the measurement of five separate samples of the same diluted aliquot. The system response was determined from the nearest available stable isotope of the nuclide of interest, as discussed in chapter 3. For example, a calibration solution with stable ^{133}Cs was used to determine the system response for ^{137}Cs, and a combination of neodymium and samarium was used to determine the response for ^{148}Nd. By simply multiplying the raw count data by the system response, the concentration in ppb could be determined for the isobars at a given mass. Because this represented a diluted sample, the dilution factor (DF) had to be multiplied by this concentration to get the original concentration of the sample sent for mass spectroscopy. After this was taken in to account, the remaining concentration was multiplied by the fissio-genic ratio to arrive at the final estimate for the concentration of the given nuclide of interest.

Table 20 Mass spectroscopy measurement data for dissolved DUO_2 pellet

Mass	Nuclides	Raw Counts (cps)	System Response (ppb/cps)	±	Original Concentration (110.68 DF) (ppb)	±	Fissio-genic Ratio
85	Rb	1016	2.06E-05	1.72E-06	2.32	0.21	1
90	Sr (Zr)	13296	2.08E-05	1.60E-06	30.54	2.37	0.97
125	Sb (Te)	110	2.92E-05	2.09E-06	0.36	0.04	0.64
134	Cs (Ba)	1290	1.18E-05	9.99E-07	1.68	0.15	0.96
137	Cs (Ba)	37988	1.18E-05	9.99E-07	49.49	4.21	0.55
144	Ce (Te)	27121	1.10E-05	3.83E-07	32.91	1.17	0.19
147	Pm (Sm)	12814	1.07E-05	2.72E-07	15.16	0.41	0.62
148	Nd (Sm)	12497	1.06E-05	3.24E-07	14.69	0.47	0.95
150	Sm (Nd)	13483	1.04E-05	3.93E-07	15.55	0.60	0.49
154	Eu (Sm)	2518	9.50E-06	9.16E-07	2.65	0.26	0.09
235	U	605072	1.19E-05	1.43E-07	798.2	9.64	1
238	U	209413045	1.20E-05	1.22E-08	277019	284	1
239	Pu	3257585	1.20E-05	8.96E-07	4325	323	1
240	Pu	269436	1.21E-05	7.97E-07	361	23.8	1
241	Pu	103927	1.25E-05	7.49E-07	144	8.62	1
242	Pu	6003	1.21E-05	1.32E-06	8.04	0.88	1

This fissio-genic ratio represents the portion of the particular mass produced via fission that can be attributed to the nuclide of concern, and was taken by looking at the decay-corrected simulation results. For example, according to the simulation, only 55% of the mass 137 isobars were cesium – 45% were barium. In order to obtain accurate results, this ratio had to be taken into account.

A dry run of the experiment using just the chemicals used for dissolution revealed that background barium was present as a contaminant. Unfortunately, the concentration of the barium varied wildly from around 2 ppb to over 400 ppb. It appeared to be related to the concentration of the HNO_3 used, and the amount of time the acid was in contact with the vial. A background barium concentration of ~31 ppb was assumed for the presented mass spectroscopy results, because it fell within this range, and gave the most consistent results for both the ^{134}Cs and ^{137}Cs measurements. In the future, the radiochemical laboratory at Texas A&M will use pure chemicals to avoid this kind of interference. Fortunately, the only other background contaminant discovered was neodymium, which had concentrations of less than 4 ppb, which would contribute less than 0.2 ppb to the only neodymium isotope measured in this work (^{148}Nd).

Another source of possible error came with respect to the volumes measured at the University of Missouri, which were significantly less than the volumes sent. It was noted that some of the samples leaked upon being placed in a centrifuge after transit. There was some concern that some evaporation could affect the concentration measurements of the samples sent. However, a simple equilibrium calculation utilizing the ideal gas law revealed that the maximum amount of evaporation would be less than 0.45% of the volume, and thus was not a significant concern.

After the concentrations of all the nuclides of interest in the sample were determined, they were compared to the concentrations predicted by the MCNPX simulation. To accomplish this, the mass or concentration of each nuclide was divided by the mass or concentration of the total amount of plutonium. For the mass spectroscopy data, the concentration of plutonium for the sample measured was 4831 ± 324 ppb. This translates to 0.196 ± 0.013 mg of Pu in the total pellet compared to 0.198 mg as predicted by the simulation. The comparison of the resulting ratios is displayed in Table 21. As mentioned previously, the ^{125}Sb results deviate from the simulation very strongly, but all of the other ratios agree within 3% to 7 %.

Table 21 Comparison of mass spectroscopic measurements to simulation

Isotope	HFIR Decay Corrected (g/gPu)	Mass Spectroscopy Measurements (ppb)	Uncertainty (ppb)	Mass Spec Results (g/gPu)	Uncertainty (g/gPu)	S/E
^{137}Cs	9.82E-03	44.16	4.04	9.14E-03	1.04E-03	1.07
^{144}Ce	1.25E-03	6.25	0.22	1.29E-03	9.82E-05	0.96
^{134}Cs	9.83E-05	0.512	0.083	1.06E-04	1.85E-05	0.93
^{125}Sb	9.95E-05	0.357	0.042	7.38E-05	1.01E-05	1.35
^{154}Eu	4.68E-05	0.238	0.023	4.93E-05	5.88E-06	0.95
^{239}Pu	8.70E-01	4325	323	8.95E-01	8.99E-02	0.97
^{85}Rb	4.69E-04	2.32	0.21	4.79E-04	5.35E-05	0.98
^{148}Nd	3.05E-03	13.95	0.44	2.89E-03	2.14E-04	1.05
^{147}Pm	1.88E-03	9.40	0.25	1.95E-03	1.41E-04	0.97
^{150}Sm	1.66E-03	7.62	0.30	1.58E-03	1.22E-04	1.05

Although the total amount of plutonium predicted from the simulation matched within 1% the amount predicted from the HFIR MCNPX simulation, the plutonium vector did not match up nearly as well. Table 22 displays the composition of the plutonium as measured by mass spectroscopy compared to the model. Although the ^{239}Pu and ^{240}Pu values agree fairly well, the higher isotopes disagree significantly, although this is in large part due to the very small concentrations of ^{241}Pu and ^{242}Pu relative to the total plutonium vector.

Because these higher isotopes have such small quantities, the uncertainty on these values from both the simulation and the measurement could be much larger.

Table 22 Plutonium vector comparison to simulation

	HFIR Simulation Pu Vector	Mass Spectroscopy Pu vector	S/E
^{239}Pu	87.1%	89.4%	0.97
^{240}Pu	8.27%	7.46%	1.11
^{241}Pu	4.38%	2.99%	1.46
^{242}Pu	0.25%	0.17%	1.47

With the comparison between the gamma and mass spectroscopic measurements completed, a three-way comparison was made to ensure that the results were consistent across both measurement techniques and the HFIR MCNPX simulation. These results are displayed in Fig. 20 for five of the isotopes that were measured with gamma spectroscopy. This comparison serves to illustrate that there is reasonably good agreement for all of the nuclides identified as possible source attribution signatures, excluding ^{125}Sb. Both measurement techniques agree with respect to this nuclide within their respective uncertainties, but the value from the simulation vastly over predicts the concentration of this nuclide.

The plutonium vector comparison and the three-way comparison illustrate that perhaps the higher plutonium isotopics and one of the fission-product signatures (^{125}Sb) may not serve as effective discriminators for source attribution. When dealing with low-burnup material, the concentration of ^{242}Pu is extremely low – leading to high levels of uncertainty. It is also fairly clear that the ability to model ^{125}Sb, at least with the methods used in this work, is prone to vast over-prediction – which could lead to problems if this simulation method is used to populate a library and this isotope is used for source attribution.

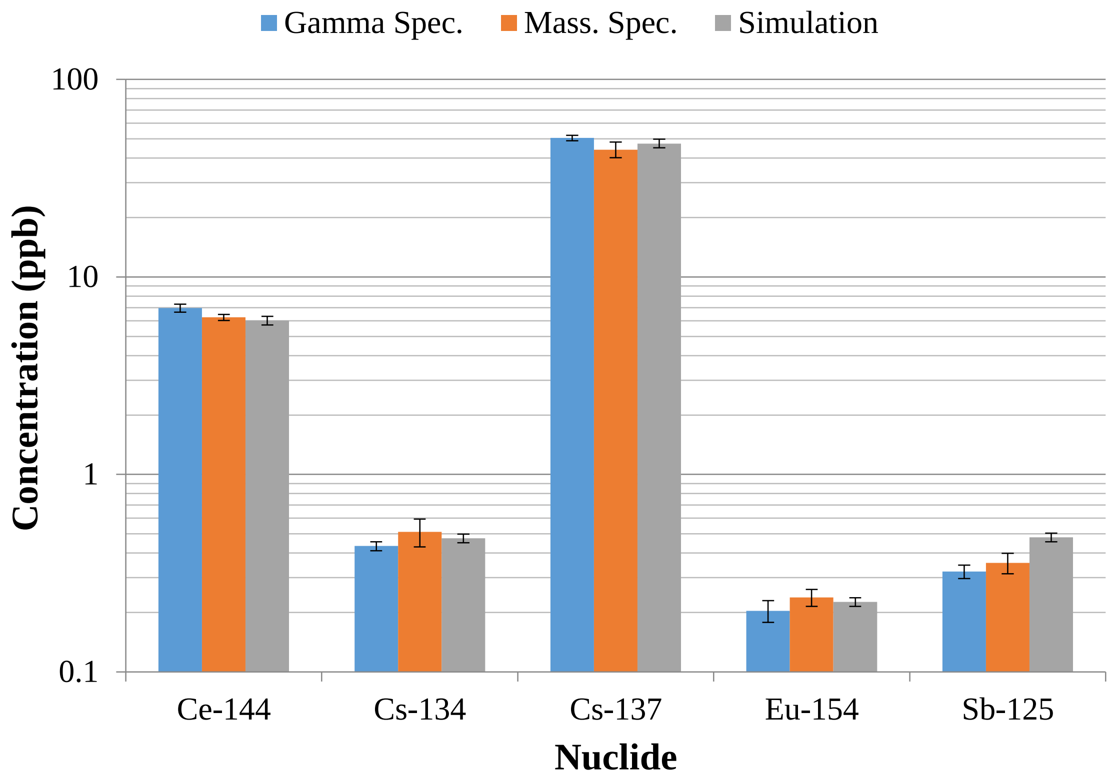


Figure 20: The three-way comparison between both analytical measurement techniques and simulation for five key nuclides.

V.E. Burnup Calculations

The final calculations presented in this chapter will be the burnup calculations as predicted by each measurement technique and the simulation. As discussed in chapter 3, the burnup or exposure (GWd/MTU) of irradiated fuel can be calculated by measuring the quantity of ^{137}Cs in the sample.[46] The ^{137}Cs nuclide is a widely accepted indicator of fuel burnup because its neutron absorption cross sections are negligible, its yields from both ^{235}U and ^{239}Pu are approximately the same, and its 30 year half-life makes a correction for reactor power history unnecessary. Another nuclide that has been used for burnup determination is ^{148}Nd. This nuclide also has similar yields for fast and thermal fission of ^{239}Pu and ^{235}U, and is stable – meaning no correction for decay needs to be accounted for. However, there are some radiative capture pathways that can lead to the production of ^{148}Nd aside from fission. This makes ^{148}Nd slightly less predictable for the prediction of burnup. The data for the burnup calculation was taken from the previous sections, including the mass spectroscopic measurements, gamma measurements, and the MCNPX simulation results.

Both the gamma data (Ci/gmDUO^2) and the mass data (ppb) had to be converted in to acceptable units and converted in to exposure given some basic assumptions. For example, the burnup calculations assumed a recoverable energy per fission of 198.5 MeV, and cumulative fission yields of 6.50% and 1.66% for ^{137}Cs and ^{148}Nd respectively. These values were retrieved from information from the National Nuclear Data Center, Berkley Lab, and the Korea Atomic Energy Research Institute websites.[47,56,57] All of the fission-product yields and energy per fission data assumed the fissioning of ^{239}Pu at fast neutron energies (~1.0 MeV).

Table 23 Burnup calculations from each source

Method	Isotope	Burnup (GWd/MTU)	±
Mass Spectroscopy	^{137}Cs	3.97	0.41
Mass Spectroscopy	^{148}Nd	4.54	0.43
Gamma Spectroscopy	^{137}Cs	4.57	0.33
Simulation	^{137}Cs	4.29	0.21
Simulation	^{148}Nd	4.79	0.24
	Average	**4.43**	**0.31**

The burnup calculation results are displayed in Table 23 for each of the measurement and simulation methods. The mass spectroscopy and simulation methods use both ^{137}Cs and ^{148}Nd to predict the burnup, although it is clear that the ^{148}Nd method over-predicts the burnup calculated by the ^{137}Cs values by about 12%. This is probably due to some contribution to the nuclide outside of fission directly populating the 148 mass chain. The average from all five methods yields a burnup of 4.43 ± 0.31 GWd/MTU. This is significantly higher than the requested burnup of 1 GWd/MTU, but the irradiation produced nearly 200 μg of 89% ^{239}Pu – which is very close to weapons grade material. Chapter VI will describe how well this compares to the material produced in the simulation of the PHWR natural UO_2 fuel (thermal neutron spectrum) and the blanket of the FBR model (fast neutron spectrum).

VI. CONCLUSIONS AND EXAMPLE METHODOLOGY FOR ATTRIBUTION

Ultimately, the tasks of this research were: to use MCNPX to simulate the DUO_2 irradiation in the HFIR, use gamma-ray and mass spectroscopy to measure the concentrations of all of the isotopes identified as 'indicators' in the previous computational work, compare the results of all three methods, and propose a preliminary methodology for attributing plutonium to a source reactor using the results as a demonstration. The comparison of the results built confidence in the MCNPX models being used in this project and served as a data point in the library of reactor types to demonstrate the methodology that could be used to identify the source reactor of weapons grade plutonium. This chapter will summarize the work, introduce and demonstrate the mentioned attribution methodology, and discuss how the work can be continued to provide an experimental demonstration of the methodology using the nuclide ratios presented in Table 3. Before jumping into the attribution methodology, a conclusive summary on the results obtained from the fast neutron irradiation simulation of the DUO_2 samples and those from the gamma spectroscopic and mass spectroscopic measurements are presented in the following section VI.A.

VI.A. Conclusions

The first effort undertaken in this work was the development of a Monte-Carlo simulation that was used to predict the nuclide concentrations within the DUO_2 fuel samples irradiated in the HFIR in a specially created fast neutron environment. Two relatively small adjustments to the simulation were made before there was suitable agreement between the simulation predictions and the initial gamma-ray spectroscopy measurements – shifting the irradiation capsule to an average position at the bottom-most fuel sample, and the extension of the irradiation time to 0.93% greater than the reported EFPDs from ORNL. The agreement between the final measurement results and the final simulation predictions was good enough (to within 5-10% for most nuclides) to lend confidence to the models, and validate the adjustments that were made to the final model. The simulation results served to illuminate how the burnup within the fuel samples evolved, by tracking the buildup of ^{137}Cs, which led to the understanding of how sensitive the nuclide inventory was to the irradiation time (or power) in this experiment – most of the burnup was occurring in the last part of the irradiation.

The simulation results also served to demonstrate the similarities and differences between the neutron spectra within the experimental capsule and that in the blanket of an FBR. Specifically, that although the thermal component of the neutron spectra was reduced drastically, the epithermal contribution was significantly higher than what is typical in an FBR. The simulation results were also the basis for the determination of the fast-to-thermal ratio calculated for the HFIR irradiation; a value of ~200 vs. less than 1 for a typical thermal reactor and over 50,000 for a typical FBR. Once again, this bears out that the fuel samples were irradiated in a 'fast' spectrum, but certainly not one that could be considered identical to that in an FBR. Finally, the simulation results predicted that the pellet achieved a burnup of 4.29 GWd/MTU and produced 198 μg of plutonium consisting of ~87% ^{239}Pu.

The mass spectroscopy measurements confirmed that ~196 μg of plutonium (~89% ^{239}Pu) was bred into the interrogated fuel sample pellet – accounting for about 1.8% of the original uranium mass. This is considerably more than what would be achieved in a typical thermal reactor, especially considering the estimated burnup of 4.43 GWd/MTU. For most of the cases, both the gamma and mass spectroscopy measurements agreed well, and matched with the simulation predictions. There were two primary outliers when the measurements were compared to the simulation – ^{125}Sb and ^{242}Pu. This disagreement was the basis for the recommendation that ^{125}Sb (which is well-known for being difficult to model) and ^{242}Pu (small quantities and high uncertainty) not be used as an indicator element in the proposed attribution methodology described in section VI.B.

The gamma-ray spectroscopy measurements served as the first concrete indication that the irradiated fuel samples significantly surpassed the requested burnup of ~1 GWd/MTU; predicting a burnup of ~4.57 GWd/MTU. The predicted activities also served as a second analytical measurement to corroborate the mass spectroscopy measurements, and ultimately helped determine that ^{125}Sb should not be used as an indicator element using the proposed methodology.

Finally, all of the simulation work and measurements described can serve as a demonstration for some of the techniques that could be used to determine characteristics of weapons-grade plutonium for nuclear forensics. All of the results presented were also used to demonstrate the methodology presented in the following section that could be used to inform (among other information) a decision on the source of the plutonium.

VI.B. Example Methodology

The proposed attribution methodology first requires that the investigators obtain some or all of the nuclide ratios presented in Table 3. The first measurements could likely utilize gamma spectroscopy to estimate the concentration of the radioactive nuclides, along with gravimetric measurements to estimate the amount of plutonium. Depending on the size and form of the interdicted plutonium, some self-absorption corrections may need to be taken in to account. Once a sample has been analyzed with mass spectroscopy, all of the nuclide ratios in Table 3 should be easy to measure and quantify with reasonably low uncertainties. As demonstrated from the results of this study, it could be wise to eliminate some troublesome or unreliable ratios, such as the ratios including ^{125}Sb and ^{242}Pu, which could be prone to simulation errors or extremely low signals.

Once all of the nuclide ratios have been measured and their uncertainty quantified, the ratios will be entered as a vector **r**, and compared to the same ratios from each model (M) in a library that was built previously. Ideally, the library would have all of the nuclide ratios of interest calculated for multiple reactor types at numerous burnups. The probability of model M matching the given measured vector **r** is proportional to the probability of observing measured values **r** given model M, which is given by Eq. (21).[58]

$$P(\boldsymbol{r}|M) = \prod_{j=1}^{n} \frac{1}{\sigma_j\sqrt{2\pi}} exp\left\{-\frac{(\boldsymbol{r}_j - \boldsymbol{r}_m)^2}{2{\sigma_j}^2}\right\} \tag{21}$$

where:

P(**r**|M) = the probability of observing measured values **r** given the model M

$\mathbf{r}_j$ = the j^{th} nuclide ratio in a vector of n measured nuclide ratios

σ_j = the uncertainty associated with the jth nuclide ratio from vector **r**

$\mathbf{r}_m$ = the j^{th} nuclide ratio in a vector of n simulated nuclide ratios from model M

n = the number nuclide ratios being compared

This treatment follows from Bayes theorem[59,60], assuming that the prior probability for each model is identical (a uniform prior). By computing this ‘likelihood’ for each model, and comparing them, it is elementary to determine which model has the maximum likelihood - the model that best fits the measured data. This will also give some indication of any other models that could also be likely, even if they aren't the 'most' likely. This information can hopefully be combined with other intelligence to inform decision-makers about what type of reactor most likely produced the interdicted plutonium.

As an example, a 'toy' version of this methodology is presented in Table 24. The data gleaned from the mass spectroscopy results shown in Chapter V is used as the measurement data for the interdicted plutonium. Here, only four models are compared, including data produced using modifications of the PHWR and FBR models created by T. Coles and J. Osborn, where the irradiations were lengthened to produce material matching the approximate burnup of the material produced experimentally in this work (~4.4 GWd/MTU). One of the HFIR models is the final version, whereas one is a previous simulation, where the irradiation time was 50 days rather than 50.7 days. The maximum likelihood calculations are given at the bottom of the table, with the likelihood under the data representing the best possible match, where the data itself was used as a library. Obviously, this would never occur in a real situation, but it is presented simply for comparison.

A 'normalized' case is also given, where the maximum likelihood was normalized to the largest likelihood value calculated among all the models, since the actual number calculated doesn't necessarily have a useful meaning – only the relative values hold weight.

Another second likelihood calculation was conducted where three ratios (the 3 that matched the worst with the measurement) were removed; these were the ^{125}Sb, ^{242}Pu, and ^{90}Sr data. With these relative 'outliers' removed, the improved HFIR model came surprisingly close to the maximum likelihood, especially considering there were still nine data points in the calculation. Figures 21, 22 and 23 give a graphical representation of the measurement and HFIR simulation data represented as Gaussian distributions. The overlap of each distribution with the measurement distribution represents the relative ‘likelihood’ that the measurement is consistent with the simulation for a given nuclide. Here, the standard deviation used for the measurement was the measurement error, and a 5% error was assumed for the MCNPX HFIR data.

Table 24 Maximum likelihood data and calculation

Isotope	**PHWR Sim. @ 4.29 GWd/MTU (g/gPu)**	**FBR Sim. @ 4.47 GWd/MTU (g/gPu)**	**HFIR Sim. (g/gPu)**	**Corrected HFIR Sim. (g/gPu)**	**Mass Spectroscopy Data (g/gPu)**	**Error (g/gPu)**
^{137}Cs	5.24E-02	6.38E-03	8.54E-03	9.82E-03	9.14E-03	1.04E-03
^{144}Ce	8.52E-03	5.29E-04	1.07E-03	1.25E-03	1.29E-03	9.82E-05
^{134}Cs	6.08E-04	7.74E-05	8.97E-05	9.83E-05	1.06E-04	1.85E-05
^{125}Sb	2.67E-04	5.60E-05	8.75E-05	9.95E-05	7.38E-05	1.01E-05
^{154}Eu	2.48E-04	4.14E-05	4.17E-05	4.68E-05	4.93E-05	5.88E-06
^{239}Pu	8.28E-01	9.66E-01	8.83E-01	8.70E-01	8.95E-01	8.99E-02
^{242}Pu	3.08E-03	1.08E-05	1.80E-03	2.52E-03	1.66E-03	2.14E-04
^{85}Rb	4.35E-03	3.65E-04	4.14E-04	4.69E-04	4.79E-04	5.35E-05
^{90}Sr	2.57E-02	1.90E-03	2.14E-03	2.44E-03	6.13E-03	6.30E-04
^{148}Nd	1.74E-02	2.12E-03	2.65E-03	3.05E-03	2.89E-03	2.14E-04
^{147}Pm	1.04E-02	1.23E-03	1.64E-03	1.88E-03	1.95E-03	1.41E-04
^{150}Sm	1.02E-02	1.81E-04	1.37E-03	1.66E-03	1.58E-03	1.22E-04
Calculated Likelihood	**<1E-100**	**6.20E-37**	**3.95E27**	**8.36E27**	**6.07E40***	
Normalized	**~0**	**~0**	**0.472**	**1**		
Likelihood (w/o Sb, Sr, and ^{242}Pu)	**<1E-100**	**3.05E-24**	**1.35E26**	**4.13E29**	**1.30E30***	
Normalized	**~0**	**~0**	**0.0003**	**1**		

*Note – This likelihood was calculated using the mass spectroscopy data itself

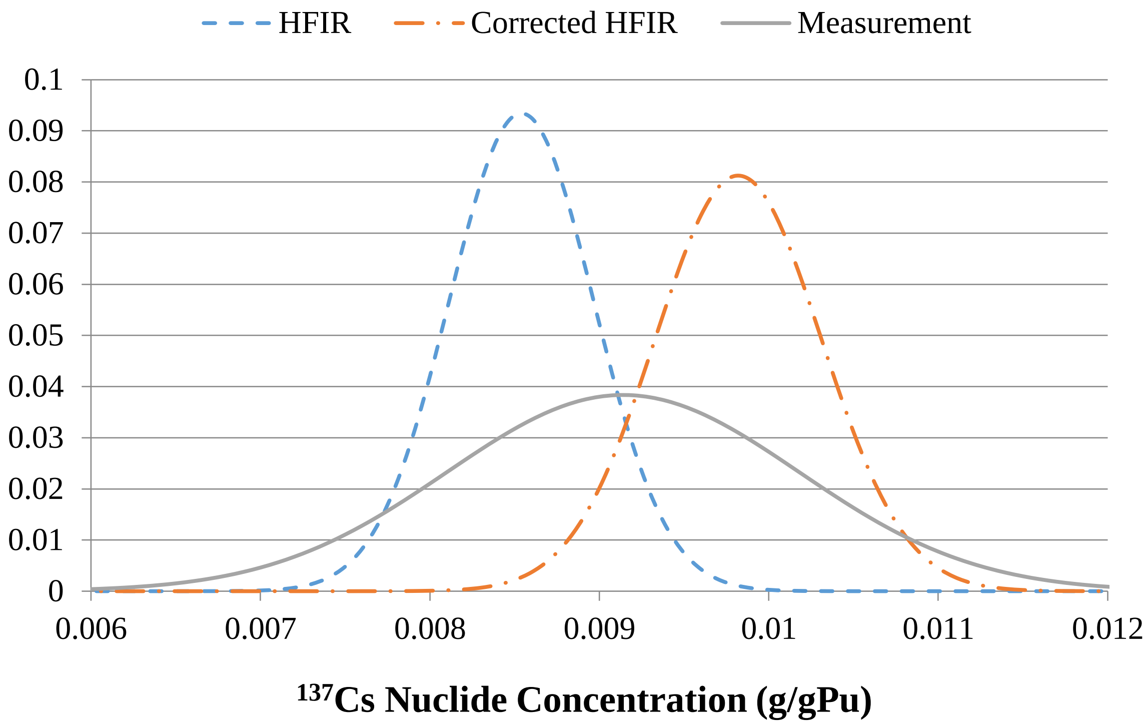


Figure 21: Comparison of ^{137}Cs nuclide concentration.

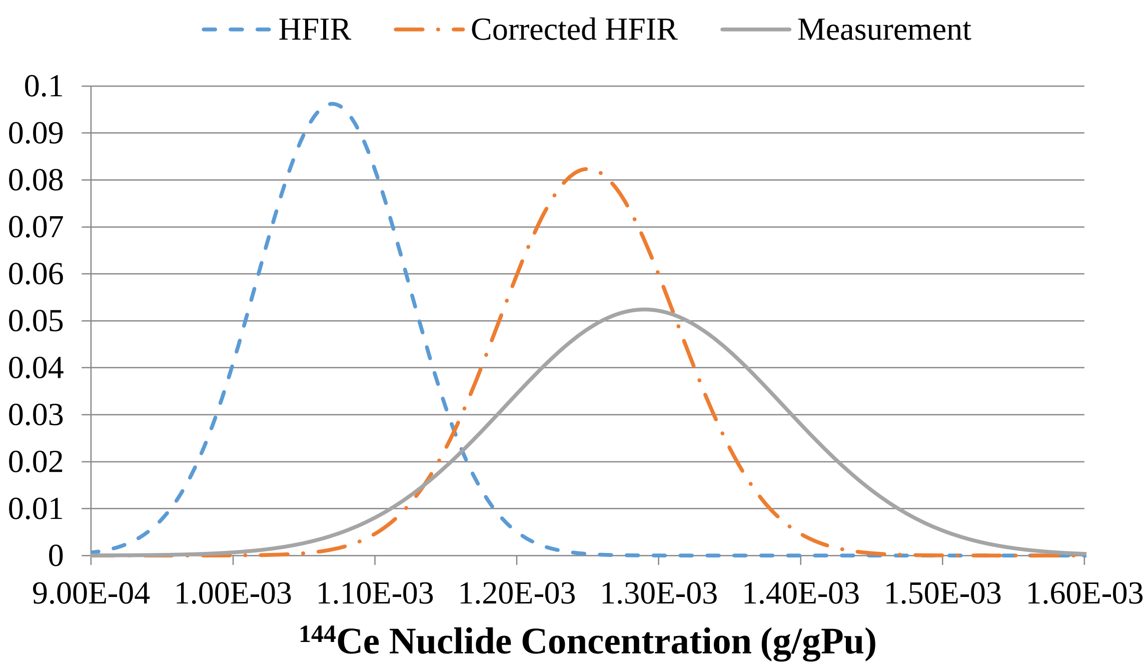


Figure 22: Comparison of ^{144}Ce nuclide concentration.

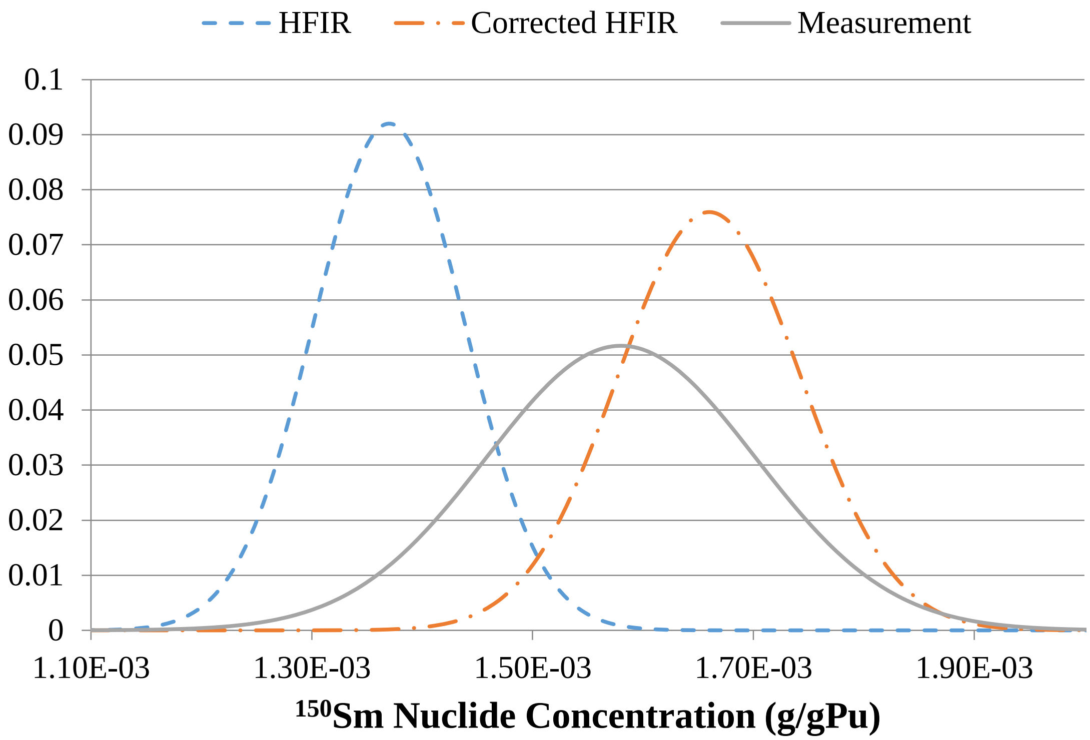


Figure 23: Comparison of ^{150}Sm nuclide concentration.

For the mass spectroscopy data measured while executing this work and the 'library' presented here, the 'Corrected' HFIR simulation yielded the highest likelihood with the earlier HFIR model coming in second. These results should be expected, since the 'Corrected' HFIR simulation was specifically built to emulate the actual irradiation. However, it does show that the calculation yields the expected results, and that the previous HFIR model had a 'likelihood' on the same order (or within a few orders). Both the PHWR and FBR results were effectively zero when compared to the much more representative HFIR models. Again, this is to be expected considering the vast difference in the neutron spectrum, as discussed in section IV.F.

It is obvious that although one of the goals of this effort was to emulate DUO_2 irradiated in the blanket region of an FBR, the burnup was far too high for this. Blanket material in an FBR would never reach over 4 GWd/MTU for operation reasons. However, it is interesting to note that even though the neutron spectrum in the FBR was notably different than the spectrum used to irradiate the samples in this work, the measured ratios presented in Table 24 still match the FBR simulation better than the PHWR by many orders of magnitude. The calculated likelihoods for the FBR model were small, but much larger than the likelihoods calculated for the PHWR model - meaning that the match with the FBR, although poor, is still many orders of magnitude better than the match with the PHWR simulation. If the library had just contained these two reactors, it would be clear that the irradiation was much closer to that in an FBR than fuel in a PHWR.

Aside from demonstrating the likelihood calculation, this exercise serves to demonstrate the importance of having a robust library for this method to be effective. If none of the simulations are reasonably close to the actual reactor, then the prediction has little meaning – for example, if the program only had the PHWR results and a set of PWR results, one of them would match better than the other – but neither would be even remotely close to the actual reactor. The maximum likelihood approach simply indicates which set of simulated data matches the best with the measured data, given an accurate determination of the uncertainty of this measurement. It can also show the relative match between several models, in the case that several could match reasonably well. It should also be noted that the determination of the uncertainty in this method is almost as important as an accurate determination of the actual concentration.

Another consideration that could be the focus of future work would be an investigation in to the possibility that multiple isotopes yield very similar information. Although nine independent isotopic ratios would serve as a very robust indicator, if several of the isotopes behave similarly as a function of reactor type, burnup, neutron energy spectrum, and cooling time, then these isotopes should be removed from the methodology.

VI.C. Future Work

The next major thrust of this research already being pursued involves an irradiation similar to the one described in this work, but in a thermal neutron spectrum using natural uranium samples. These will not have a gadolinium sheath, and will thus serve as the experimental samples simulating a Pressurized Heavy Water Reactor (PHWR). An MCNPX model for these samples will need to be developed, and another suite of experimental measurements will need to be taken. The results from both the ‘FBR’ and ‘PHWR’ samples can then be scrutinized and compared using the specific isotope signatures identified in the research that let do this work - including the plutonium vector and the fission-product contaminants. Hopefully, the results will confirm that the specific ratios outlined can in fact be used as a signature to identify what kind of reactor was used to produce the irradiated fuel that supplied the weapons-grade plutonium.

REFERENCES

1. Allison G. Nuclear deterrence in the age of nuclear terrorism. *Technol Rev*. 2008;111(6):68-73,7.

2. Nuclear forensics and attribution act. 2010; 111-140 (111th Congress).

3. Kazi R. Efficacy of nuclear forensics. *Strategic Analysis*. 2011;35(4):576-580.

4. Arbuckle L. *The deterrence of nuclear terrorism through an attribution capability.* Naval Postgraduate School; 2008.

5. Mark JC, Von Hippel F, Lyman E. Explosive properties of reactor-grade plutonium. *Science and Global Security*. 2009;17(2-3):170-185.

6. Benedict M. *Nuclear chemical engineering.* New York: McGraw-Hill; 1981.

7. Agrawal S. India and the United States: A new partnership. *The International spectator*. 2011;46(2):57-73.

8. Bajaj SS. The Indian PHWR. *Nucl Eng Des*. 2006;236(7):701-722.

9. Chetal SC. The design of the prototype fast breeder reactor. *Nucl Eng Des*. 2006;236(7):852-860.

10. Glaser A. Isotopic signatures of weapon-grade plutonium from dedicated natural uranium-fueled production reactors and their relevance for nuclear forensic analysis. *Nucl Sci Eng*. 2009;163(1):26-33.

11. Glaser A. Weapon-grade plutonium production potential in the indian prototype fast breeder reactor. *Science & global security*. 2007;15(2):85-105.

12. Squassoni S. India's nuclear separation plan: Issues and views. Lib. of Congress 2006.

13. WNA. Fast neutron reactors. http://www.world-nuclear.org/info/Current-and-Future-Generation/Fast-Neutron-Reactors/#.UbYnaPk3t8E. Updated 2014.

14. Chirayath S. Neutronic and nonproliferation characteristics of (PuO_2–UO_2) and (PuO_2–ThO_2) as fast reactor fuels. *Nucl Eng Des*. 2009;239(10):1916-1924.

15. Delves D. *IAEA safety glossary : Terminology used in nuclear safety and radiation protection.* Vienna, Austria : International Atomic Energy Agency, 2007; 2007 ed; 2007. http://lib-ezproxy.tamu.edu:2048/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=cat03318a&AN=tamug.2932018&site=eds-live.

16. Charlton W. Operator declaration verification technique for spent fuel at reprocessing facilities. *Nuclear instruments & methods in physics research.Section B, Beam interactions with materials and atoms*. 2000;168(1):98-108.

17. Jones A. Classification of spent reactor fuel for nuclear forensics. *Anal Chem*. 2014;86(11):5399-405.

18. Scott M. Nuclear forensics: Attributing the source of spent fuel used in an RDD event. 2013; LA-UR-13-25153.

19. Mayer K. Unveiling the history of seized plutonium through nuclear forensic investigations. *Radiochimica Acta*. 2009; 97(4):261-264.

20. Wallenius M. Age determination of plutonium material in nuclear forensics by thermal ionisation mass spectrometry. *Fresenius J Anal Chem*. 2000; 366(3):234-238. doi: 10.1007/s002160050046.

21. Sturm M, Richter S, Aregbe Y, et al. Feasibility study for the development of plutonium reference materials for age dating in nuclear forensics. *IAEA Safeguards Symposium*. 2010.

22. Wallenius M. The "age" of plutonium particles. *Radiochimica Acta*. 2001;89(1):55.

23. Kristo M. The state of nuclear forensics. *Nuclear instruments & methods in physics research.Section B, Beam interactions with materials and atoms*. 2013;294:656-661.

24. Mayer K. Nuclear forensic science-from cradle to maturity. *J Alloys Compounds*. 2007;444-445:50-56.

25. Mayer K. Nuclear forensics—a methodology providing clues on the origin of illicitly trafficked nuclear materials. *Analyst*. 2005;130(4):433-441.

26. Mayer K. Nuclear forensics: A methodology applicable to nuclear security and to non-proliferation. *Journal of physics.Conference series*. 2011;312(6).

27. Moody KJ. *Nuclear forensic analysis.* Boca Raton, Fla.: CRC Press; 2005.

28. WNA. Safeguards to prevent nuclear proliferation. http://www.world-nuclear.org/info/Safety-and-Security/Non-Proliferation/Safeguards-to-Prevent-Nuclear-Proliferation/#.Ubom_Pk3t8E. Updated 2012.

29. Wallenius M. Nuclear forensic investigations with a focus on plutonium. *J Alloys Compounds*. 2007;444-445:57-62.

30. Weaver J. Assessment of non-traditional isotopic ratios by mass spectrometry for analysis of nuclear activities. *J Radioanal Nucl*. 2009;282(3):709-713.

31. Coles TM. *Computational nuclear forensics analysis of weapons-grade plutonium separated from fuel irradiated in a thermal reactor.* [Master of Science]. Texas A&M University; 2014.

32. Osborn J. *Trace fission product ratios for nuclear forensics attribution of weapons-grade plutonium from fast breeder reactor blankets.* [Master of Science]. Texas A&M University; 2014.

33. Breismeister JF. MCNP - A general Monte-Carlo N-particle transport code. 2003;LA-UR-03-2003.

34. Pelowitz DB. MCNPX user's manual. April 2008;LA-CP-07-1473.

35. Fahey A, Zeissler CJ, Newbury D, Davis J, Lindstrom RM. Postdetonation nuclear debris for attribution. *Proc Natl Acad Sci U S A*. 2010;107(47):20207-20212. doi: 10.1073/pnas.1010631107.

36. Charlton W. *Noble gas measurement and analysis technique for monitoring reprocessing facilities.* [Doctor of Philosophy]. Texas A&M University; 1999.

37. Chirayath SS. Trace fission product ratios for nuclear forensics attribution of weapons-grade plutonium from fast and thermal reactors. *Science & global security*. 2014.

38. Osborn JM, Chirayath SS, Charlton WS. Neutronics analysis of fast breeder reactor core to support the plutonium fingerprinting for forensics (PuFF) project.

39. Osborn JM, Coles TM, Twaddle AR, Chirayath SS, Charlton WS. Nuclear forensics signature analysis of fast and thermal reactor produced weapons-grade plutonium. . 2013;245(Abstracts of Papers of the American Chemical Society).

40. Brown FB, Nagaya Y. The MCNP5 random number generator. *American Nuclear Society 2002 Winter Meeting*. 2002;LA-UR-02-3782.

41. Wilson W, Cowell S, England T, Hayes A, Moller P. A manual for CINDER'90 version 07.4 codes and data. *Manual LA-UR*. 2007:07-8412.

42. England TR. CINDER--A ONE- POINT DEPLETION AND FISSION PRODUCT PROGRAM. 1962;WAPD-TM-334.

43. Wilson WB, England TR, Arthur ED. Accelerator transmutation studies at los alamos with LAHET, MCNP, and CINDER`90. *Simulating accelerator radiation environments workshop*. 1993;LA-UR-93-3080.

44. Fensin M. *Development of the MCNPX depletion capability: A Monte-Carlo linked depletion method that automates the coupling between MCNPX and CINDER90 for high fidelity burnup calculations.* [Doctor of Philosophy]. University of Florida; 2008.

45. Duderstadt J, Hamilton L. *Nuclear reactor analysis.* Ann Arbor, Michigan: John Wiley & Sons; 1976.

46. Reilly D, Ensslin N, Smith Jr H, Kreiner S. Passive nondestructive assay of nuclear materials. *Passive Nondestructive Assay of Nuclear Materials (PANDA) Manual*. 1991;LA-UR-90-732.

47. Korea atomic energy research institute nuclear data center table of nuclides. http://atom.kaeri.re.kr/ton/nuc8.html. Updated 2000. Accessed 07/2015, 2015.

48. Knoll GF. *Radiation detection and measurement.* 4th ed. John Wiley & Sons; 2010.

49. Canberra hig-purity germanium detectors, standard electrode coaxial ge detectors (SEGe). http://www.canberra.com/products/detectors/germanium-detectors.asp. Updated 2015. Accessed 07/2015, 2015.

50. Primm III RT, Xoubi N. Modeling of the high flux isotope reactor cycle 400. *ORNL/TM-2004/251, Oak Ridge National Laboratory*. 2005;ORNL/TM-2004/251.

51. Scale: A comprehensive modeling and simulation suite for nuclear safety analysis and design. 2011;ORNL/TM-2005/39.

52. Chirayath SS, Osborn JM, Coles TM. Trace fission product ratios for nuclear forensics attribution of weapons-grade plutonium from fast and thermal reactors. *Science and Global Security*. 2015;23(1):48-67. http://lib-ezproxy.tamu.edu:2048/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=edselc&AN=edselc.2-52.0-84924455339&site=eds-live. doi: 10.1080/08929882.2015.996079.

53. Bell GL, McDuffee JL, Ellis RJ. Fabrication and irradiation of depleted uranium dioxide disks. 2013;ORNL/TM-2013/344.

54. Manohar S. A gamma-spectrometric method for the determination of plutonium isotope ratios. *Journal of radioanalytical chemistry*. 1981;63(1):145-153.

55. Sanders C, Gauld I. *Isotopic analysis of high-burnup PWR spent fuel samples from the takahama-3 reactor.* Division of Systems Analysis and Regulatory Effectiveness, Office of Nuclear Regulatory Research, US Nuclear Regulatory Commission; 2003.

56. Cumulative fission yields. https://www-nds.iaea.org/sgnucdat/c3.htm. Updated 20062015.

57. Fission product yields. http://ie.lbl.gov/fission.html. Updated 11 December, 19982015.

58. Burr TL, Charlton WS, Nakhleh CW. Assessing confidence in inferring reactor type and fuel burnup: A markov chain Monte-Carlo approach. *Nuclear Instruments and Methods in*

Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. 2005;555(1):426-434.

59. Mr. Bayes, Price M. An essay towards solving a problem in the doctrine of chances. by the late rev. mr. bayes, FRS communicated by mr. price, in a letter to john canton, AMFRS. *Philosophical Transactions (1683-1775)*. 1763:370-418.

60. Nakhleh CW. Plausible inference and the interpretation of quantitative data. 1998;LA-13412-MS.

APPENDIX A

Enregistrement : LSE/LD/024-4

AREVA NC Pierrelatte Service L S E	DOSSIER RECETTE	LSE : n°06 / 10 Compte rendu : Page 2/4 Révision 0

CONTROLES CHIMIQUES DE LA POUDRE

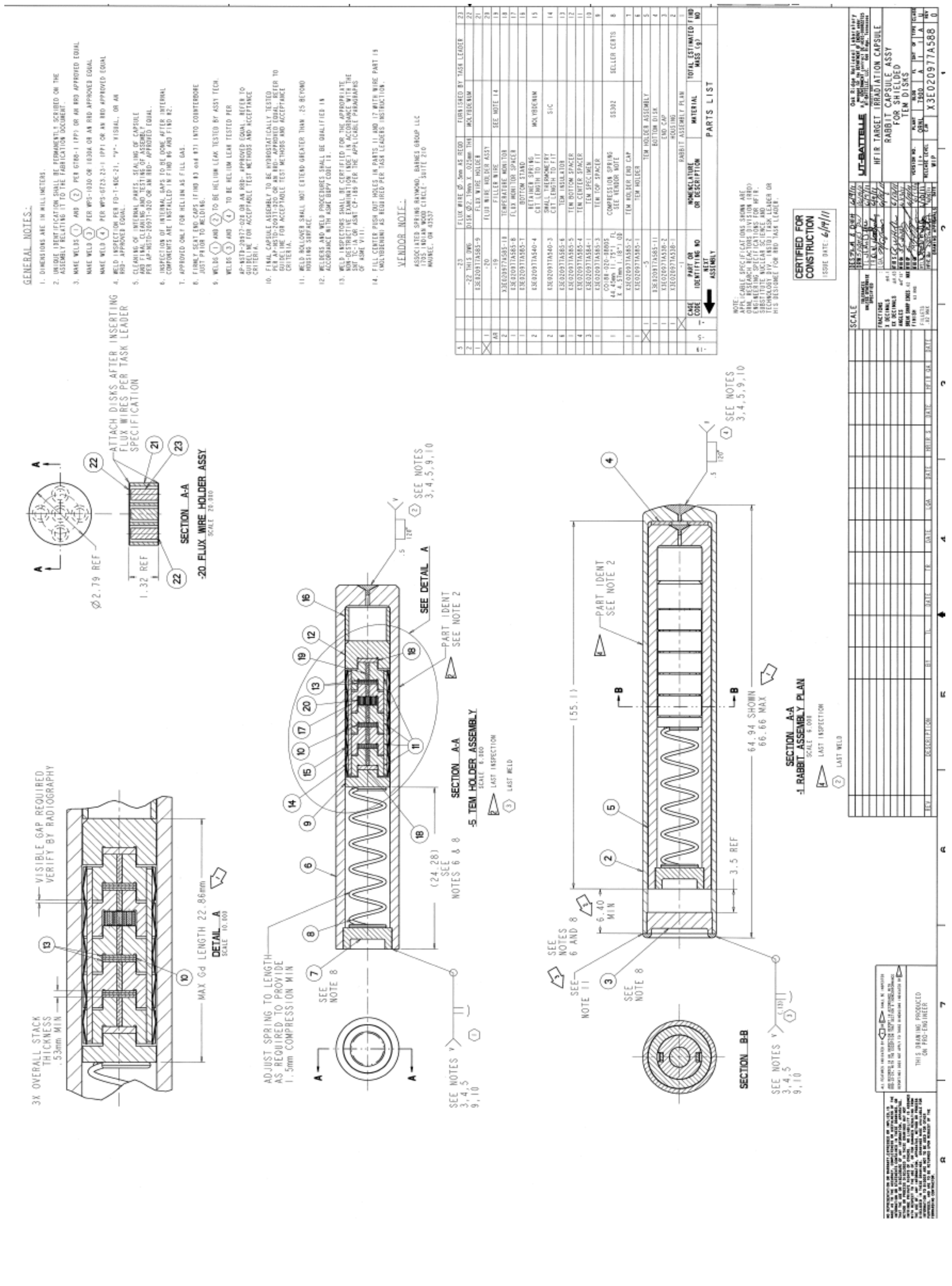
Réf.Spéc.	CONTRÔLE	unité	LIMITES SPEC. mini	maxi	RESULTATS du LOT lot N°797	VERIFICATION	OBSERVATION
2.1.	**Teneur en Uranium**						
	U	% masse	87,4	*****	87,72		
2.2.	**Composition Isotopique**						
2.2.4.	U_{232}	% masse			< 1.10^{-9}		
	U_{234}	% masse			0,0011		
2.2.3.	U_{235}	% masse	A-0,02	A+0,02	0,2562		
	U_{236}	% masse			≤ 0,0003		
	U_{238}	% masse			99,7424		
2.3.	**Rapport Oxygène/Métal**						
	O/U		2,04	2,12	2,07		
2.4.	**Teneur en humidité**						
	H_2O	µg/gU	****	3000	799		
2.5.	**Teneur en impuretés**						
		µg/gU					
2.5.1.	Al		****	100	< 1		
	B		****	0,5	< 0,2		
	Bi		****	4	< 1		
	Ca		****	100	< 1		
	Cd		****	1	< 0,2		
	Co		****	25	< 1		
	Cr		****	150	< 2		
	Cu		****	100	< 5		
	Fe		****	150	6		
	In		****	5	< 1		
	Mg		****	50	< 1		
	Mn		****	100	< 1		
	Mo		****	100	< 1		
	Ni		****	100	4		
	Nb		****	100	< 0,2		
	P		****	100	< 10		
	Pb		****	100	< 4		
	Li		****	100	< 0,2		
	Si		****	75	≤ 1		
	Ag		****	10	< 2		
	Na		****	50	< 1		
	Ta		****	50	< 0,2		
	Sn		****	25	< 1		
	Ti		****	50	< 2		
	Th		****	5	< 1		
	V		****	1,5	< 1		
	W		****	50	< 0,5		
	Zn		****	50	< 1		
	C		****	100	20		
	Cl		****	20	< 10		
	F		****	50	< 10		
	N		****	30	< 10		
	Gd		****	0,1	< 0,1		
	Sm		****		< 0,1		
	Dy		****		< 0,1		
	Eu		****		< 0,1		
	Gd+Sm+Dy+Eu		****	0,6	0,4		
2.5.2.	**Somme des Impuretés**	µg/gU	****	1500	≤ **100,9**		
2.5.3.	**Equivalent Bore**	µg/gU	****	1	≤ **0,9199**		

Destinataire : DCI/TU

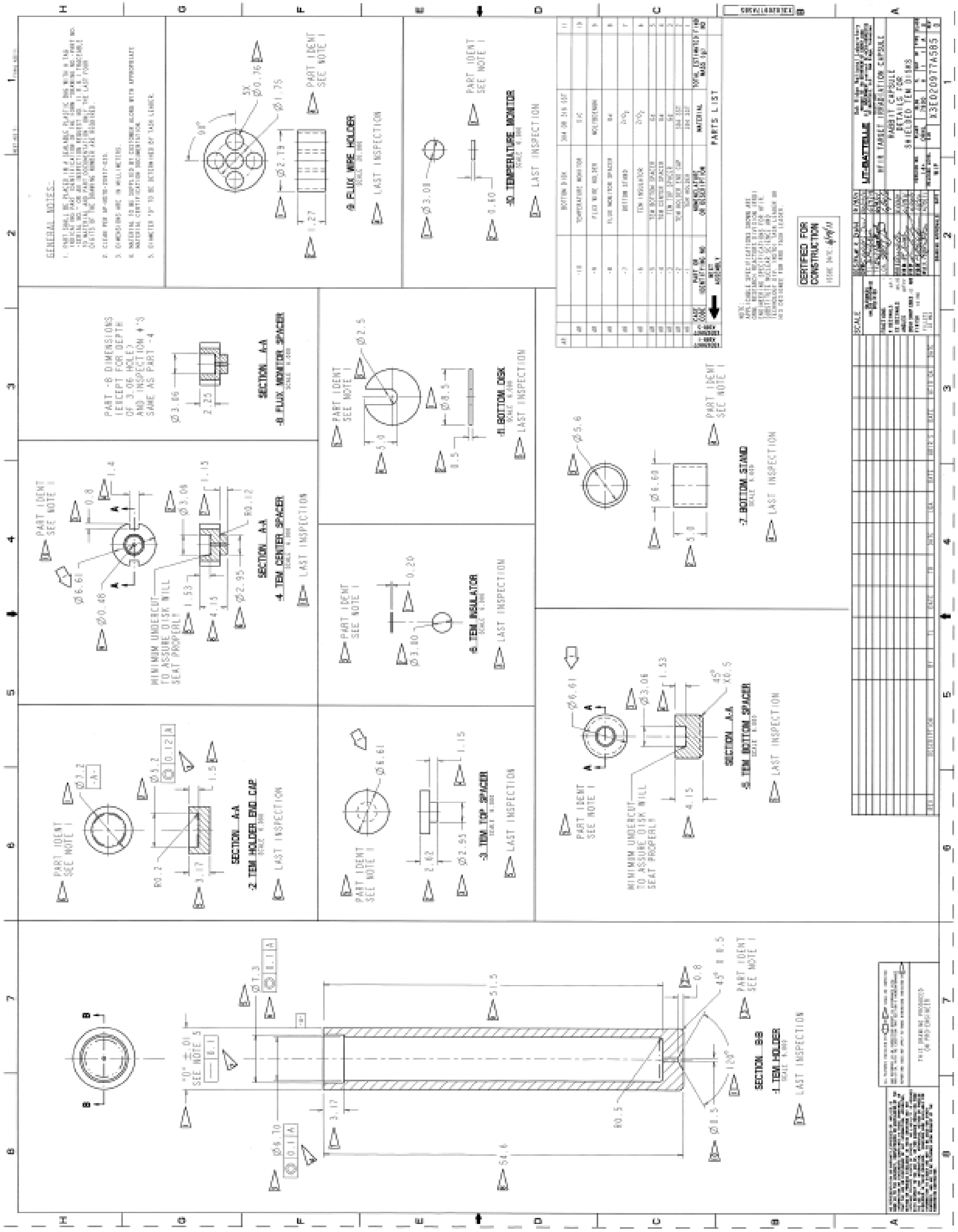
Classement : DCI/TU

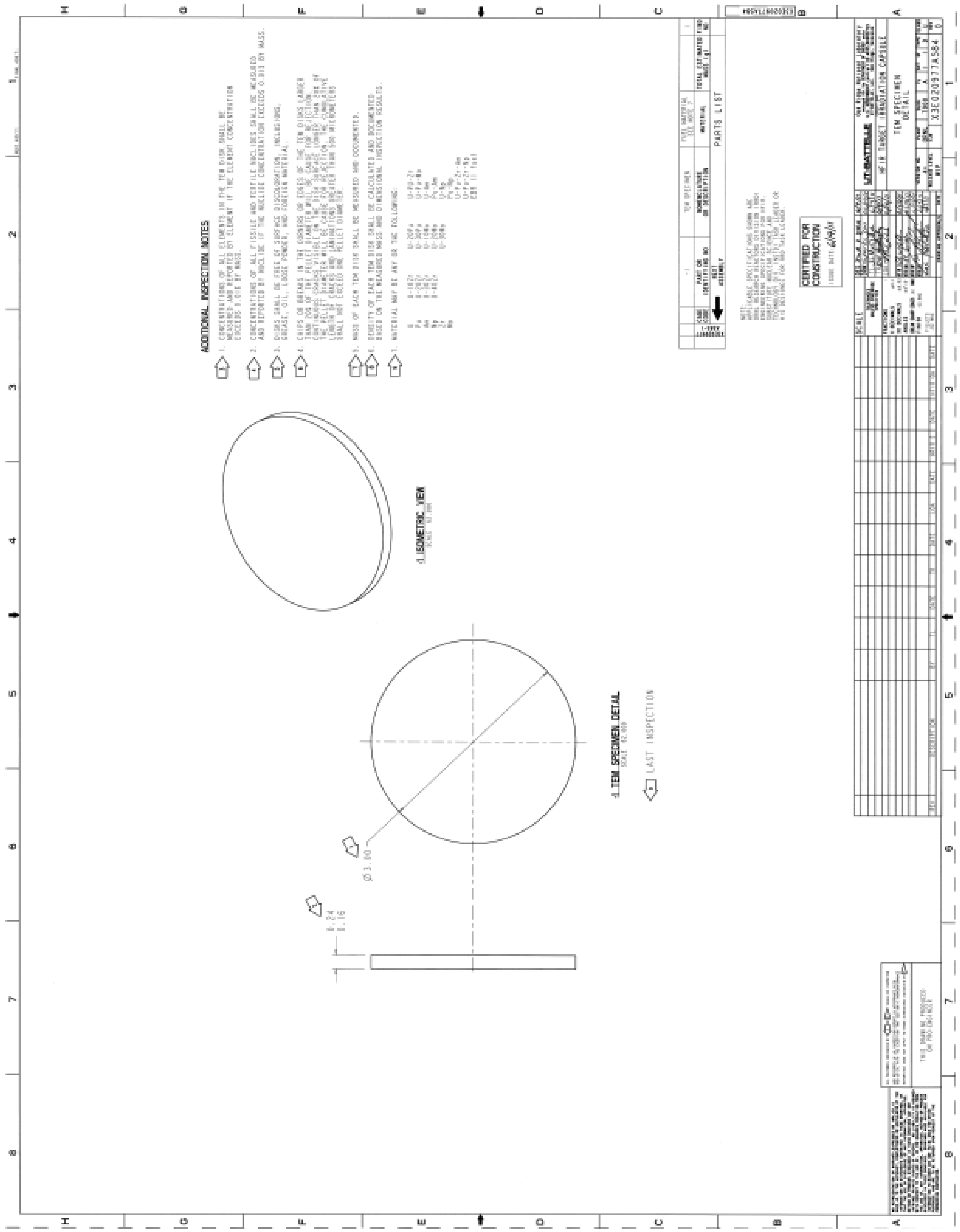
Durée archivage : Cf.Procédure AQ de DCI/TU n° Q0 1776

APPENDIX B



GENERAL NOTES:
VENDOR NOTE:
DETAIL A
SECTION A-A
-20 FLUX WIRE HOLDER ASSY
-5 TEM HOLDER ASSEMBLY
-1 RABBIT ASSEMBLY PLAN
SECTION B-B
PARTS LIST
CERTIFIED FOR CONSTRUCTION
HFIR TARGET IRRADIATION CAPSULE
RABBIT CAPSULE ASSY
FOR SHIELDED
TEM DISKS
THIS DRAWING PRODUCED ON PRO-ENGINEER




ADDITIONAL INSPECTION NOTES
ISOMETRIC VIEW
TEM SPECIMEN DETAIL
LAST INSPECTION
PARTS LIST
CERTIFIED FOR CONSTRUCTION
HFIR TARGET IRRADIATION CAPSULE
TEM SPECIMEN DETAIL
X3E020977A584

APPENDIX C

```
HFIR Model version 4.0 (HFV4.0+), BOC Conditions
c 9.4kg U-235, 2.8 g B-10, 4 Al plugs
c
c   Last updated June 2008; RB positions corrected to actual loading;
c                         cell, surface, and material data modified to include
c                         19 axial layers in fuel elements instead of 7
c
c                   ____________________________________________
c                     HFIR Model version 4.0 is based on cycle 400 data
c
c                              By: Ned Xoubi and Trent Primm
c                   ____________________________________________
c
c
c      This new modified model reflects the changes in the HFIR core and is
c      also based on the older model HFIR-V.2 which was originally  developed
c      by J.C. Gehin, L.A. Smith, J.A. Bucholz (ORNL).
c
c      The MCNP model for the HFIR is divided into six regions (parts),
c          Region-1 is the flux trap target region FTT
c          Region-2 is the inner fuel element region IFE
c          Region-3 is the outer fuel element region OFE
c          Region-4 is the control element region
c          Region-5 is the removable reflector region
c          Region-6 is the Be permanent reflector region
c      Cell cards, surface cards, and parameter cards that effect the change in
c                                  each region are marked for each region.
c
c    150.00    $ upper model boundary
c   -150.00    $ lower model boundary
c    Axial midplane - 0.0 - is at the axial mid-line of the core
c
c
c     ----------------------------------------
c                    REGION 1
c
c         FLUX TRAP TARGET REGION (FTT)
C      ----------------------------------------
c
c  The Flux Trap Target Region has 31 Sites in interior of basket and
c                                6 Sites on periphery of basket.
c  Target  region contains a typical experimental loading of curium targets,
c    experiment targets (aluminum + stainless steel),a hydraulic tube, and
c    an internal reflector (Be-pins).
```

```
c  Unused sites are defined as dummy targets, and are loaded with Aluminum
c     target (solid and shrouded).
c
c
c     --------------------
c     Region 1  Cell Cards
c     --------------------
c
c     Target site A-2  (shrouded Al dummy)
410   512 4.82102E-02   -410 +427  -428            imp:n=1    $ Dummy Al target material
411   511 6.03240E-02   -411 +410  +427  -428        imp:n=1    $ Dummy Al target tube
412   25  6.02083E-02   #(-411 +427 -428) -412 +417 -419   imp:n=1    $ outer clad and
upper & lower regions
413   25  6.02083E-02   +413 -414  +416  -418            imp:n=1    $ outer shroud
414   2   9.95227E-02   +412 -415  +417  -419
 (-413:414:-416:418)              imp:n=1    $ coolant
c
c     Target site A-3  (shrouded Al dummy)
420   512 4.82102E-02   -420 +427  -428                imp:n=1    $ Dummy Al target material
421   511 6.03240E-02   -421 +420  +427  -428            imp:n=1    $ Dummy Al target tube
422   25  6.02083E-02   #(-421 +427 -428) -422 +417 -419   imp:n=1    $ outer clad and
upper & lower regions
423   25  6.02083E-02   +423 -424  +416  -418            imp:n=1    $ outer shroud
424   2   9.95227E-02   +422 -425  +417  -419
                   (-423:424:-416:418)              imp:n=1    $ coolant
c
c     Target site B-1  (shrouded Al dummy)
430   512 4.82102E-02   -430 +427  -428                imp:n=1    $ Dummy Al target material
431   511 6.03240E-02   -431 +430  +427 -428            imp:n=1    $ Dummy Al target tube
432   25  6.02083E-02   #(-431 +427 -428) -432 +417 -419   imp:n=1    $ outer clad and
upper & lower regions
433   25  6.02083E-02   +433 -434  +416  -418            imp:n=1    $ outer shroud
434   2   9.95227E-02   +432 -435  +417  -419
                   (-433:434:-416:418)              imp:n=1    $ coolant
c
c     Target site B-2  (shrouded Al dummy)
440   512 4.82102E-02   -440 +427  -428                imp:n=1    $ Dummy Al target material
441   511 6.03240E-02   -441 +440  +427  -428            imp:n=1    $ Dummy Al target tube
442   25  6.02083E-02   #(-441 +427 -428) -442 +417 -419   imp:n=1    $ outer clad and
upper & lower regions
443   25  6.02083E-02   +443 -444  +416  -418            imp:n=1    $ outer shroud
444   2   9.95227E-02   +442 -445  +417  -419
                   (-443:444:-416:418)              imp:n=1    $ coolant
c
c     Target site B-3  (HT tube)
```

```
750   520  6.02423E-02   -450 +752  -751                 imp:n=1    $ target material upper
target
751   520  6.02423E-02   -450 +755  -754                 imp:n=1    $ target material
752   520  6.02423E-02   -450 +758  -757                 imp:n=1    $ target material
753   520  6.02423E-02   -450 +761  -760                 imp:n=1    $ target material
754   520  6.02423E-02   -450 +764  -763                 imp:n=1    $ target material centerline
target
755   520  6.02423E-02   -450 +767  -766                 imp:n=1    $ target material
756   520  6.02423E-02   -450 +770  -769                 imp:n=1    $ target material
757   520  6.02423E-02   -450 +773  -772                 imp:n=1    $ target material
758   520  6.02423E-02   -450 +776  -775                 imp:n=1    $ target material  lower
target
c
760   521  6.02423E-02   -451   +753  -750 (450:-752:751)   imp:n=1    $ target tube upper
target
761   521  6.02423E-02   -451   +756  -753 (450:-755:754)   imp:n=1    $ target tube
762   521  6.02423E-02   -451   +759  -756 (450:-758:757)   imp:n=1    $ target tube
763   521  6.02423E-02   -451   +762  -759 (450:-761:760)   imp:n=1    $ target tube
764   521  6.02423E-02   -451   +765  -762 (450:-764:763)   imp:n=1    $ target tube
centerline target
765   521  6.02423E-02   -451   +768  -765 (450:-767:766)   imp:n=1    $ target tube
766   521  6.02423E-02   -451   +771  -768 (450:-770:769)   imp:n=1    $ target tube
767   521  6.02423E-02   -451   +774  -771 (450:-773:772)   imp:n=1    $ target tube
768   521  6.02423E-02   -451   +777  -774 (450:-776:775)   imp:n=1    $ target tube lower
target
c
452   60   2.00000E-15   -452 +451  +777  -750            imp:n=1    $ air space
453   25   6.02083E-02   -453 +452  +777  -750            imp:n=1    $ outer clad
454   2    9.95227E-02   -454 +453  +777  -750            imp:n=1    $ coolant
c
455   25   6.02083E-02   -453 +417  -777                  imp:n=1    $ Al block -  below core
456   2    9.95227E-02   -454 +453  +417  -777            imp:n=1    $ coolant - below core
c
446   60   2.00000E-15   -451 +750  -419                  imp:n=1    $ target and tube - above
targets (air)
447   60   2.00000E-15   -452 +451  +750  -419            imp:n=1    $ air space - above core
448   25   6.02083E-02   -453 +452  +750  -419            imp:n=1    $ outer clad - above core
449   2    9.95227E-02   -454 +453  +750  -419            imp:n=1    $ coolant  - above core
c
c     Target site B-4  (shrouded Al dummy)
460   512  4.82102E-02   -460 +427  -428                  imp:n=1    $ Dummy Al target material
461   511  6.03240E-02   -461 +460  +427  -428            imp:n=1    $ Dummy Al target tube
462   25   6.02083E-02   #(-461 +427 -428) -462 +417 -419   imp:n=1    $ outer clad and
upper & lower regions
463   25   6.02083E-02   +463 -464  +416  -418            imp:n=1    $ outer shroud
464   2    9.95227E-02   +462 -465  +417  -419
```

```
                  (-463:464:-416:418)              imp:n=1    $ coolant
c
c    Target site B-5  (shrouded Al dummy)
470   512  4.82102E-02   -470 +427  -428                 imp:n=1    $ Dummy Al target material
471   511  6.03240E-02   -471 +470  +427  -428           imp:n=1    $ Dummy Al targe tube
472   25   6.02083E-02   #(-471 +427 -428) -472 +417 -419   imp:n=1    $ outer clad and
upper & lower regions
473   25   6.02083E-02   +473 -474  +416  -418           imp:n=1    $ outer shroud
474   2    9.95227E-02   +472 -475  +417  -419
                  (-473:474:-416:418)              imp:n=1    $ coolant
c
c    Target site C-1  (shrouded Al dummy)
480   512  4.82102E-02   -480 +427  -428                 imp:n=1    $ Dummy Al target material
481   511  6.03240E-02   -481 +480  +427  -428           imp:n=1    $ Dummy Al targe tube
482   25   6.02083E-02   #(-481 +427 -428) -482 +417 -419   imp:n=1    $ outer clad and
upper & lower regions
483   25   6.02083E-02   +483 -484  +416  -418           imp:n=1    $ outer shroud
484   2    9.95227E-02   +482 -485  +417  -419
                  (-483:484:-416:418)              imp:n=1    $ coolant
c
c    Target site C-2  (solid Al dummy)
490   530   6.02423E-02   -492  +417  -419               imp:n=1    $ solid Al dummy outer
clad and upper & lower regions
491   530   6.02423E-02   +492 -494  -418 +416           imp:n=1    $ solid Al dummy outer
shroud
492   2     9.95227E-02   #491 +492 -495 +417 -419         imp:n=1    $ coolant
c
c    Target site C-3  (shrouded Al dummy)
510   512  4.82102E-02   -510 +427  -428                 imp:n=1    $ Dummy Al target material
511   511  6.03240E-02   -511 +510  +427  -428           imp:n=1    $ Dummy Al target tube
512   25   6.02083E-02   #(-511 +427 -428) -512 +417 -419   imp:n=1    $ outer clad and
upper & lower regions
513   25   6.02083E-02   +513 -514  +416  -418           imp:n=1    $ outer shroud
514   2    9.95227E-02    +512 -515  +417  -419
                  (-513:514:-416:418)              imp:n=1    $ coolant
c
c    Target site C-4  (shrouded Al dummy)
520   512  4.82102E-02   -520 +427  -428                 imp:n=1    $ Dummy Al target material
521   511  6.03240E-02   -521 +520  +427  -428           imp:n=1    $ Dummy Al target tube
522   25   6.02083E-02   #(-521 +427 -428) -522 +417 -419   imp:n=1    $ outer clad and
upper & lower regions
523   25   6.02083E-02    +523 -524  +416  -418          imp:n=1    $ outer shroud
524   2    9.95227E-02    +522 -525  +417  -419
                  (-523:524:-416:418)              imp:n=1    $ coolant
c
```

```
c    ( TAMU Rabbit dimensions modeled by Mathew Swinney in comm. w/ Joel McDuffee 6/13/2013 )
c    Target site C-5
530   530   6.02423E-02   -532  +417 -419 #(-810 778 -530)  imp:n=1    $ solid Al dummy outer clad and upper & lower regions
531   530   6.02423E-02   +532 -534  -418 +416            imp:n=1    $ solid Al dummy outer shroud
532   2     9.95227E-02   #531 +532 -535 +417 -419         imp:n=1    $ coolant
533   530   6.02423E-02   -530 778 -810 #(-531 779 -809)    imp:n=1    $ Al Housing
534   532   -4.43         (-531 779 -808 #(-536 780 -807) #(-539 829 -808)):
                          (-536 537 780 -781)              imp:n=1    $ Ti-Alloy Holder and Bottom Stand
535   60    2E-15         (-531 808 -809):(-536 806 -807):
                          (-537 780 -781):(801 -802 -538):
                          (785 -786 -538):(789 -790 -538):
                          (793 -794 -538):(797 -798 -538):
                          (-536 816 -815 811 -813 814):
                          (-536 816 -815 -812 -813 814):
                          (-536 533 816 -817):
                          (-536 533 818 -819):
                          (-536 533 822 -823):
                          (-536 533 824 -825):
                          (-536 533 826 -827):
                          (-536 533 828 -815):
                          (-539 829 -808)                  imp:n=1    $ Air Voids
537   533   -7.9          -536 781 -806 #535 #538 #539 vol=0.65485 imp:n=1 $ Gd Spacers
538   534   -10.5         (-533 783 -784):(-533 787 -788):
                          (-533 791 -792):(-533 795 -796):
                          (-533 799 -800):(-533 803 -804)
                           imp:n=1 vol=0.008825  $ TEM Samples
539   536   -5.68         (-533 782 -783):(-533 784 -785):
                          (-533 786 -787):(-533 788 -789):
                          (-533 790 -791):(-533 792 -793):
                          (-533 794 -795):(-533 796 -797):
                          (-533 798 -799):(-533 800 -801):
                          (-533 802 -803):(-533 804 -805)
                           imp:n=1  vol=0.01765  $ TEM Insulators
c
c
c    Target site C-6  JP-26 (solid SST-304)
c    Jp-26 & Jp-27 solid SSt targets in Al holders (dimensions communication w/ Randy Hobbs 8/9/2004)
c
540   535   5.97E-02      -542 +427 -428                  imp:n=1    $ sst targets in Al holder
542   25    6.02083E-02   #(-542 +427 -428) -542 +417 -419  imp:n=1    $ Holder  upper & lower regions
543   25    6.02423E-02   +543 -544  -418 +416            imp:n=1    $ outer shroud Al
```

```
544   2    9.95227E-02   542 -543  +417 -419             imp:n=1    $ coolant
545   2    9.95227E-02   #543 543 -545  +417 -419         imp:n=1    $ coolant
c
c
c    Target site D-2  (shrouded Al dummy)
550   512   4.82102E-02   -550 +427  -428                imp:n=1    $ Al dummy target material
551   511   6.03240E-02   -551 +550  +427  -428           imp:n=1    $ Al dummy target tube
552   25    6.02083E-02   #(-551 +427 -428) -552 +417 -419  imp:n=1    $ outer clad and
upper & lower regions
553   25    6.02083E-02    +553 -554  +416  -418          imp:n=1    $ outer shroud
554   2    9.95227E-02    +552 -555  +417  -419
                 (-553:554:-416:418)              imp:n=1    $ coolant
c
c    Target site D-3  (solid Al dummy)
560   530   6.02423E-02   -562  +417  -419               imp:n=1    $ outer clad and upper &
lower regions
561   530   6.02423E-02   +562 -564  -418 +416            imp:n=1    $ outer shroud
562   2    9.95227E-02   #561 +562 -565 +417 -419         imp:n=1    $ coolant
c
c    Target site D-4  (solid Al dummy)
570   530   6.02423E-02   -572   +820  -419              imp:n=1    $ outer clad and upper &
lower regions
578   530   6.02423E-02   -572  +417 -821                imp:n=1    $ outer clad and upper &
lower regions
579   530   6.02423E-02   -572  +821 -820                imp:n=1    $ sample cell for flux tallies
at midplane
571   530   6.02423E-02   +572 -574  -418 +416            imp:n=1    $ outer shroud
572   2    9.95227E-02   #571 +572 -575 +417 -419         imp:n=1    $ coolant
c
c    Target site D-5  (shrouded Al dummy)
580   512   4.82102E-02   -580 +427  -428                imp:n=1    $ Al dummy target material
581   511   6.03240E-02   -581 +580  +427  -428           imp:n=1    $ Al dummy target tube
582   25    6.02083E-02   #(-581 +427 -428) -582 +417 -419  imp:n=1    $ outer clad and
upper & lower regions
583   25    6.02083E-02   +583 -584  +416  -418           imp:n=1    $ outer shroud
584   2    9.95227E-02   +582 -585  +417  -419
                  (-583:584:-416:418)             imp:n=1    $ coolant
c
c    Target site D-6  (shrouded Al dummy)
590   512  4.82102E-02   -590 +427  -428                 imp:n=1    $ Al dummy target material
591   511  6.03240E-02   -591 +590  +427  -428            imp:n=1    $ Al dummy target tube
592   25   6.02083E-02   #(-591 +427 -428) -592 +417 -419   imp:n=1    $ outer clad and
upper & lower regions
593   25   6.02083E-02   +593 -594  +416  -418            imp:n=1    $ outer shroud
594   2    9.95227E-02   +592 -595  +417  -419
                 (-593:594:-416:418)              imp:n=1    $ coolant
```

c
c Target site E-2 (JP-27 SST-304 targets)
c Jp-26 & Jp-27 solid SSt targets in Al holders (dimensions communication w/ Randy Hobbs 8/9/2004)
c
610 535 5.97E-02 -612 +427 -428 imp:n=1 $ sst targets in Al holder
612 25 6.02083E-02 #(-612 +427 -428) -612 +417 -419 imp:n=1 $ Holder upper & lower regions
613 25 6.02423E-02 +613 -614 -418 +416 imp:n=1 $ outer shroud Al
614 2 9.95227E-02 612 -613 +417 -419 imp:n=1 $ coolant
615 2 9.95227E-02 #613 613 -615 +417 -419 imp:n=1 $ coolant
c
c Target site E-3 (shrouded Al dummy)
620 512 4.82102E-02 -620 +427 -428 imp:n=1 $ Al dummy target material
621 511 6.03240E-02 -621 +620 +427 -428 imp:n=1 $ Al dummy target tube
622 25 6.02083E-02 #(-621 +427 -428) -622 +417 -419 imp:n=1 $ outer clad and upper & lower regions
623 25 6.02083E-02 +623 -624 +416 -418 imp:n=1 $ outer shroud
624 2 9.95227E-02 +622 -625 +417 -419
(-623:624:-416:418) imp:n=1 $ coolant
c
c Target site E-4 (shrouded Al dummy)
630 512 4.82102E-02 -630 +427 -428 imp:n=1 $ Al dummy target material
631 511 6.03240E-02 -631 +630 +427 -428 imp:n=1 $ Al dummy target tube
632 25 6.02083E-02 #(-631 +427 -428) -632 +417 -419 imp:n=1 $ outer clad and upper & lower regions
633 25 6.02083E-02 +633 -634 +416 -418 imp:n=1 $ outer shroud
634 2 9.95227E-02 +632 -635 +417 -419
(-633:634:-416:418) imp:n=1 $ coolant
c
c Target site E-5 (solid Al dummy)
640 530 6.02423E-02 -642 +820 -419 imp:n=1 $ solid Al dummy outer clad and upper & lower regions
648 530 6.02423E-02 -642 +417 -821 imp:n=1 $ solid Al dummy outer clad and upper & lower regions
649 530 6.02423E-02 -642 +821 -820 imp:n=1 $ sampleing cell for flux tallies
641 530 6.02423E-02 +642 -644 -418 +416 imp:n=1 $ solid Al dummy outer shroud
642 2 9.95227E-02 #641 +642 -645 +417 -419 imp:n=1 $ coolant
c
c
c Target site E-6 (solid Al dummy)
650 530 6.02423E-02 -652 +417 -419 imp:n=1 $ solid Al dummy outer clad and upper & lower regions

651   530   6.02423E-02   +652 -654 -418 +416   imp:n=1 $ solid Al dummy outer shroud
652   2   9.95227E-02   #651 +652 -655 +417 -419   imp:n=1 $ coolant
c
c   Target site E-7 (shrouded Al dummy)
660   512   4.82102E-02   -660 +427 -428   imp:n=1 $ Al dummy target material
661   511   6.03240E-02   -661 +660 +427 -428   imp:n=1 $ Al dummy target tube
662   25   6.02083E-02   #(-661 +427 -428) -662 +417 -419   imp:n=1 $ outer clad and upper & lower regions
663   25   6.02083E-02   +663 -664 +416 -418   imp:n=1 $ outer shroud
664   2   9.95227E-02   +662 -665 +417 -419
                    (-663:664:-416:418)   imp:n=1 $ coolant
c
c   Target site F-3 (shrouded Al dummy)
670   512 4.82102E-02   -670 +427 -428   imp:n=1 $ Al dummy target material
671   511 6.02423E-02   -671 +670 +427 -428   imp:n=1 $ Al dummy target tube
672   25   6.02083E-02   #(-671 +427 -428) -672 +417 -419   imp:n=1 $ outer clad and upper & lower regions
673   25   6.02083E-02   +673 -674 +416 -418   imp:n=1 $ outer shroud
674   2   9.95227E-02   +672 -675 +417 -419
                   (-673:674:-416:418)   imp:n=1 $ coolant
c
c   Target site F-4 ((shrouded Al dummy)
680   512 4.82102E-02   -680 +427 -428   imp:n=1 $ Al dummy target material
681   511 6.02423E-02   -681 +680 +427 -428   imp:n=1 $ Al dummy target tube
682   25   6.02083E-02   #(-681 +427 -428) -682 +417 -419   imp:n=1 $ outer clad and upper & lower regions
683   25   6.02083E-02   +683 -684 +416 -418   imp:n=1 $ outer shroud
684   2   9.95227E-02   +682 -685 +417 -419
                   (-683:684:-416:418)   imp:n=1 $ coolant
c
c   Target site F-5 (solid Al dummy)
690   530   6.02423E-02   -692 +417 -419   imp:n=1 $ solid Al dummy outer clad and upper & lower regions
691   530   6.02423E-02   +692 -694 -418 +416   imp:n=1 $ solid Al dummy outer shroud
692   2   9.95227E-02   #691 +692 -695 +417 -419   imp:n=1 $ coolant
c
c   Target site F-6 (shrouded Al dummy)
710   512 4.82102E-02   -710 +427 -821   imp:n=1 $ shrouded Al target material
718   512 4.82102E-02   -710 +820 -428   imp:n=1 $ shrouded Al target material
719   512 4.82102E-02   -710 +821 -820   imp:n=1 $ shrouded Al target material

711 511 6.03240E-02 -711 +710 +427 -428 imp:n=1 $ shrouded Al target tube
712 25 6.02083E-02 #(-711 +427 -428) -712 +417 -419 imp:n=1 $ outer clad and upper & lower regions
713 25 6.02083E-02 +713 -714 +416 -418 imp:n=1 $ outer shroud
714 2 9.95227E-02 +712 -715 +417 -419
(-713:714:-416:418) imp:n=1 $ coolant
c
c Target site F-7 (shrouded Al dummy)
720 512 4.82102E-02 -720 +427 -428 imp:n=1 $ shrouded Al target material
721 511 6.03240E-02 -721 +720 +427 -428 imp:n=1 $ shrouded Al target tube
722 25 6.02083E-02 #(-721 +427 -428) -722 +417 -419 imp:n=1 $ outer clad and upper & lower regions
723 25 6.02083E-02 +723 -724 +416 -418 imp:n=1 $ outer shroud
724 2 9.95227E-02 +722 -725 +417 -419
(-723:724:-416:418) imp:n=1 $ coolant
c
c Target site G-5 (shrouded Al dummy)
730 512 4.82102E-02 -730 +427 -428 imp:n=1 $ shrouded Al target material
731 511 6.03240E-02 -731 +730 +427 -428 imp:n=1 $ shrouded Al target tube
732 25 6.02083E-02 #(-731 +427 -428) -732 +417 -419 imp:n=1 $ outer clad and upper & lower regions
733 25 6.02083E-02 +733 -734 +416 -418 imp:n=1 $ outer shroud
734 2 9.95227E-02 +732 -735 +417 -419
(-733:734:-416:418) imp:n=1 $ coolant
c
c Target site G-6 (solid Al dummy)
740 512 4.82102E-02 -740 +427 -428 imp:n=1 $ target material
741 511 6.03240E-02 -741 +740 +427 -428 imp:n=1 $ target tube
742 25 6.02083E-02 #(-741 +427 -428) -742 +417 -419 imp:n=1 $ outer clad and upper & lower regions
743 25 6.02083E-02 +743 -744 +416 -418 imp:n=1 $ outer shroud
744 2 9.95227E-02 +742 -745 +417 -419
(-743:744:-416:418) imp:n=1 $ coolant
c
c
c **** PTP Experimental Loading ***
c
c Target site PTP-1 (A-4)
c
811 711 5.93745E-02 -920 +970 -971 imp:n=1 $ first target capsule (bottom)
812 712 4.47398E-02 -920 +971 -972 imp:n=1 $ second target capsule

```
813   713  3.38204E-02   -920 +972 -973        imp:n=1    $ third target capsule
814   714  3.36267E-02   -920 +973 -974        imp:n=1    $ fourth target capsule
815   715  2.32122E-02   -920 +974 -975        imp:n=1    $ fifth target capsule
816   716  3.50519E-02   -920 +975 -976        imp:n=1    $ sixth target capsule
817   717  6.4716E-03   -920 +976 -977        imp:n=1    $ seventh target capsule (top)
c
920   25   6.02083E-02   -920 +977 -909        imp:n=1    $ clad upper region
921   25   6.02083E-02   -920 +908 -970        imp:n=1    $ clad lower region
922   25   6.02083E-02   +922 -923  +907 -909   imp:n=1    $ outer shroud
923   2    9.95227E-02   +920 -924  +908 -909
                   (-922:923:-907)        imp:n=1    $ coolant
924   2    9.95227E-02   -924  +909  -419      imp:n=1    $ coolant (above)
925   2    9.95227E-02   -924  +417  -908      imp:n=1    $ coolant (below)
c
c    Target site PTP-2  (D-1)
c
821   721  5.65355E-02   -940 +970 -971        imp:n=1    $ first target capsule (bottom)
822   722  6.00000E-02   -940 +971 -972        imp:n=1    $ second target capsule
823   723  5.93745E-02   -940 +972 -973        imp:n=1    $ third target capsule
824   724  5.89491E-02   -940 +973 -974        imp:n=1    $ fourth target capsule
825   725  5.89252E-02   -940 +974 -975        imp:n=1    $ fifth target capsule
826   726  5.93745E-02   -940 +975 -976        imp:n=1    $ sixth target capsule
827   727  6.03159E-02   -940 +976 -977        imp:n=1    $ seventh target capsule (top)
c
940   25  6.02083E-02   -940 +977 -909        imp:n=1    $ clad upper region
941   25  6.02083E-02   -940 +908 -970        imp:n=1    $ clad lower region
942   25  6.02083E-02   +942 -943  +907 -909    imp:n=1    $ outer shroud
943   2   9.95227E-02    +940 -944  +908 -909
                   (-942:943:-907)        imp:n=1    $ coolant
944   2   9.95227E-02    -944  +909  -419     imp:n=1    $ coolant (above)
945   2   9.95227E-02    -944  +417  -908     imp:n=1    $ coolant (below)
c
c    Target site PTP-3 (A-1)
c
831   731  5.64033E-02   -930 +970 -971        imp:n=1    $ first target capsule (bottom)
832   732  6.0000E-02   -930 +971 -972        imp:n=1    $ second target capsule
833   733  5.93745E-02   -930 +972 -973        imp:n=1    $ third target capsule
834   734  2.59550E-02   -930 +973 -974        imp:n=1    $ fourth target capsule
835   735  2.32314E-02   -930 +974 -975        imp:n=1    $ fifth target capsule
836   736  5.93745E-02   -930 +975 -976        imp:n=1    $ sixth target capsule
837   737  5.98973E-02   -930 +976 -977        imp:n=1    $ seventh target capsule (top)
c
930   25  6.02083E-02   -930 +977 -909        imp:n=1    $ clad upper region
931   25  6.02083E-02   -930 +908 -970        imp:n=1    $ clad lower region
932   25  6.02083E-02   +932 -933  +907  -909   imp:n=1    $ outer shroud
933   2   9.95227E-02   +930 -934  +908  -909
```

```
                (-932:933:-907)        imp:n=1    $ coolant
934   2   9.95227E-02   -934  +909  -419       imp:n=1    $ coolant (above)
935   2   9.95227E-02   -934  +417  -908       imp:n=1    $ coolant (below)
c
c    Target site PTP-4 (D-7)
c
841   741  8.16415E-02   -910 +970 -971        imp:n=1    $ first target capsule (bottom)
842   742  6.00000E-02   -910 +971 -972        imp:n=1    $ second target capsule
843   743  5.93745E-02   -910 +972 -973        imp:n=1    $ third target capsule
844   744  4.89927E-02   -910 +973 -974        imp:n=1    $ fourth target capsule
845   745  4.90794E-02   -910 +974 -975        imp:n=1    $ fifth target capsule
846   746  5.93745E-02   -910 +975 -976        imp:n=1    $ sixth target capsule
847   747  5.98063E-02   -910 +976 -977        imp:n=1    $ seventh target capsule (top)
c
910   25  6.02083E-02   -910 +977 -909        imp:n=1    $ clad upper region
911   25  6.02083E-02   -910 +908 -970        imp:n=1    $ clad lower region
912   25  6.02083E-02   +912 -913  +907  -909   imp:n=1    $ outer shroud
913   2   9.95227E-02   +910 -914  +908  -909
                (-912:913:-907)        imp:n=1    $ coolant
914   2  9.95227E-02     -914  +909  -419      imp:n=1    $ coolant (above)
915   2  9.95227E-02     -914  +417  -908      imp:n=1    $ coolant (below)
c
c    Target site PTP-5 (G-7)
c
851   751  5.93745E-02   -900 +970 -971        imp:n=1    $ first target capsule (bottom)
852   752  6.0000E-02   -900 +971 -972        imp:n=1    $ second target capsule
853   753  6.00000E-02   -900 +972 -973        imp:n=1    $ third target capsule
854   754  7.00373E-02   -900 +973 -974        imp:n=1    $ fourth target capsule
855   755  7.00373E-02   -900 +974 -975        imp:n=1    $ fifth target capsule
856   756  5.93745E-02   -900 +975 -976        imp:n=1    $ sixth target capsule
857   757  6.00335E-02   -900 +976 -977        imp:n=1    $ seventh target capsule (top)
c
900   25  6.02083E-02   -900 +977 -909        imp:n=1    $ clad upper region
901   25  6.02083E-02   -900 +908 -970        imp:n=1    $ clad lower region
902   25  6.02083E-02   +902 -903  +907  -909   imp:n=1    $ outer shroud
903   2   9.95227E-02   +900 -904  +908  -909
                (-902:903:-907)        imp:n=1    $ coolant
904   2  9.95227E-02     -904  +909  -419      imp:n=1    $ coolant (above)
905   2  9.95227E-02     -904  +417  -908      imp:n=1    $ coolant (below)
c
c    Target site PTP-6 (G-4   Al dummy )
c
861   761  5.63347E-02   -950 +970 -971        imp:n=1    $ first target capsule (bottom)
862   762  4.49341E-02   -950 +971 -972        imp:n=1    $ second target capsule
863   763  3.98252E-02   -950 +972 -973        imp:n=1    $ third target capsule
864   764  8.80417E-02   -950 +973 -974        imp:n=1    $ fourth target capsule
```

```
865   765  8.80417E-02   -950 +974 -975        imp:n=1    $ fifth target capsule
866   766  5.93745E-02   -950 +975 -976        imp:n=1    $ sixth target capsule
867   767  6.02427E-02   -950 +976 -977        imp:n=1    $ seventh target capsule (top)
c
950   25  6.02083E-02   -950 +977 -909         imp:n=1    $ clad upper region
951   25  6.02083E-02   -950 +908 -970         imp:n=1    $ clad lower region
952   25  6.02083E-02   +952 -953  +907  -909   imp:n=1    $ outer shroud
953   2   9.95227E-02   +950 -954  +908  -909
                  (-952:953:-907)        imp:n=1    $ coolant
954   2  9.95227E-02     -954  +909  -419      imp:n=1    $ coolant (above)
955   2  9.95227E-02     -954  +417  -908      imp:n=1    $ coolant (below)
c
c     **** Without Target (0.75 metal-to-water)
c     800  91  8.26883E-02     -960 +908 -909
c            905  915  925  935  945  955      imp:n=1    $water inside target basket
c
800   2  9.95227E-02  -960 +417 -419 +600 +601
                575 585 595 645 655 665
               695 715 725 745 905  915     imp:n=1    $water inside target basket Quad I
801   2  9.95227E-02  -960 +417 -419 -600 +601
                575 585 595 525 535 545
                454 465 475 425 925  915    imp:n=1    $water inside target basket Quad II
802   2  9.95227E-02   -960 +417 -419 -600 -601
                575 565 555 515 495 485
                454 445 435 415 935  945    imp:n=1    $water inside target basket Quad III
803   2  9.95227E-02   -960 +417 -419 +600 -601
                 575 565 555 635 625 615
                 695 685 675 735 945 955    imp:n=1    $water inside target basket Quad IV
804   25  6.02083E-02       +417  -419
         (+960:-905:-915:-925:-935:-945:-955)
         (-961 904 914 924 934 944 954)        imp:n=1    $target basket (can between outer
clad of PTP's)
805    2  9.95227E-02      -1999 +417  -419
         (+961 904 914 924 934 944 954)        imp:n=1    $water outside target basket
c
c     1000  2  9.95227E-02    -1999  +427  -428   imp:n=1    $target area--active fuel region
1001  3  1.00053E-01    -1999  +419  -199        imp:n=1    $water above target area
1002  1  9.89921E-02    -1999  -417  +299        imp:n=1    $water below target area
c
c
c       ----------------------------------------
c                    Region II
c
c              INNER FUEL ELEMENT REGION
c       ----------------------------------------
c
```

c The inner fuel element (IFE) consists of 171 fuel plates arranged in an
c   involutes shape. Each plate contains 15.18g +-1% of U-235.
c The IFE fueled area is modeled by homogenizing the uranium, aluminum and
c   water, in 8 radial fueled regions that reflect the different U-235
c   concentrations in each fuel plate. The IFE is divided into 152 cells,
c   8 radial fueled regions and 19 axial fueled layers
c
c   ------------------
c   IFE Cell Cards
c   ------------------
c
2000 20 6.02083E-02   +1999 +200 -100 -2000 imp:n=1 $IFE inner sidewall
2100 200 8.01309E-02   +2000 +200 -100 -2001 imp:n=1 vol=575.1150 $inner unfuelled region
c
c
c   Top - Axial Layer 1 (25.4 - 25.0 cm)
2101 211 8.008040000E-02   +2001 +150 -100 -2002 imp:n=1 vol=6.6230 $ IFE radial fuelled region 1   7.14 - 7.50 cm
2102 212 8.008390000E-02   +2002 +150 -100 -2003 imp:n=1 vol=9.7389 $ IFE radial fuelled region 2   7.50 - 8.00 cm
2103 213 8.008800000E-02   +2003 +150 -100 -2004 imp:n=1 vol=10.3673 $ IFE radial fuelled region 3   8.00 - 8.50 cm
2104 214 8.009370000E-02   +2004 +150 -100 -2005 imp:n=1 vol=22.6195 $ IFE radial fuelled region 4   8.50 - 9.50 cm
2105 215 8.009930000E-02   +2005 +150 -100 -2006 imp:n=1 vol=25.1327 $ IFE radial fuelled region 5   9.50 - 10.50 cm
2106 216 8.009980000E-02   +2006 +150 -100 -2007 imp:n=1 vol=27.6460 $ IFE radial fuelled region 6   10.50 - 11.50 cm
2107 217 8.009680000E-02   +2007 +150 -100 -2008 imp:n=1 vol=14.7655 $ IFE radial fuelled region 7   11.50 - 12.00 cm
2108 218 8.009330000E-02   +2008 +150 -100 -2009 imp:n=1 vol=18.5480 $ IFE radial fuelled region 8   12.00 - 12.60 cm
c
c   Top - Axial Layer 2 (25.0 - 22.0 cm)
2111 221 8.008040000E-02   +2001 +151 -150 -2002 imp:n=1 vol=49.6723 $ IFE radial fuelled region 1   7.14 - 7.50 cm
2112 222 8.008390000E-02   +2002 +151 -150 -2003 imp:n=1 vol=73.0420 $ IFE radial fuelled region 2   7.50 - 8.00 cm
2113 223 8.008800000E-02   +2003 +151 -150 -2004 imp:n=1 vol=77.7544 $ IFE radial fuelled region 3   8.00 - 8.50 cm
2114 224 8.009370000E-02   +2004 +151 -150 -2005 imp:n=1 vol=169.6460 $ IFE radial fuelled region 4   8.50 - 9.50 cm
2115 225 8.009930000E-02   +2005 +151 -150 -2006 imp:n=1 vol=188.4960 $ IFE radial fuelled region 5   9.50 - 10.50 cm

2116 226 8.009980000E-02   +2006 +151 -150 -2007 imp:n=1 vol=207.3450 $ IFE radial fuelled region 6   10.50 - 11.50 cm
2117 227 8.009680000E-02   +2007 +151 -150 -2008 imp:n=1 vol=10.7410 $ IFE radial fuelled region 7   11.50 - 12.00 cm
2118 228 8.009330000E-02   +2008 +151 -150 -2009 imp:n=1 vol=139.1100 $ IFE radial fuelled region 8   12.00 - 12.60 cm
c
c   Top - Axial Layer 3 (22.0 - 19.0 cm)
2121 231 8.008040000E-02   +2001 +153 -151 -2002 imp:n=1 vol=49.6723 $ IFE radial fuelled region 1   7.14 - 7.50 cm
2122 232 8.008390000E-02   +2002 +153 -151 -2003 imp:n=1 vol=73.0420 $ IFE radial fuelled region 2   7.50 - 8.00 cm
2123 233 8.008800000E-02   +2003 +153 -151 -2004 imp:n=1 vol=77.7544 $ IFE radial fuelled region 3   8.00 - 8.50 cm
2124 234 8.009370000E-02   +2004 +153 -151 -2005 imp:n=1 vol=169.6460 $ IFE radial fuelled region 4   8.50 - 9.50 cm
2125 235 8.009930000E-02   +2005 +153 -151 -2006 imp:n=1 vol=188.4960 $ IFE radial fuelled region 5   9.50 - 10.50 cm
2126 236 8.009980000E-02   +2006 +153 -151 -2007 imp:n=1 vol=207.3450 $ IFE radial fuelled region 6   10.50 - 11.50 cm
2127 237 8.009680000E-02   +2007 +153 -151 -2008 imp:n=1 vol=110.7410 $ IFE radial fuelled region 7   11.50 - 12.00 cm
2128 238 8.009330000E-02   +2008 +153 -151 -2009 imp:n=1 vol=139.1100 $ IFE radial fuelled region 8   12.00 - 12.60 cm
c
c   Top - Axial Layer 4 (19.0 - 16.0 cm)
2131 241 8.008040000E-02   +2001 +154 -153 -2002 imp:n=1 vol=49.6723 $ IFE radial fuelled region 1   7.14 - 7.50 cm
2132 242 8.008390000E-02   +2002 +154 -153 -2003 imp:n=1 vol=73.0420 $ IFE radial fuelled region 2   7.50 - 8.00 cm
2133 243 8.008800000E-02   +2003 +154 -153 -2004 imp:n=1 vol=77.7544 $ IFE radial fuelled region 3   8.00 - 8.50 cm
2134 244 8.009370000E-02   +2004 +154 -153 -2005 imp:n=1 vol=169.6460 $ IFE radial fuelled region 4   8.50 - 9.50 cm
2135 245 8.009930000E-02   +2005 +154 -153 -2006 imp:n=1 vol=188.4960 $ IFE radial fuelled region 5   9.50 - 10.50 cm
2136 246 8.009980000E-02   +2006 +154 -153 -2007 imp:n=1 vol=207.3450 $ IFE radial fuelled region 6   10.50 - 11.50 cm
2137 247 8.009680000E-02   +2007 +154 -153 -2008 imp:n=1 vol=110.7410 $ IFE radial fuelled region 7   11.50 - 12.00 cm
2138 248 8.009330000E-02   +2008 +154 -153 -2009 imp:n=1 vol=139.1100 $ IFE radial fuelled region 8   12.00 - 12.60 cm
c
c   Top - Axial Layer 5 (16.0 - 13.0 cm)
2141 251 8.008040000E-02   +2001 +155 -154 -2002 imp:n=1 vol=49.6723 $ IFE radial fuelled region 1   7.14 - 7.50 cm

2142 252 8.008390000E-02 +2002 +155 -154 -2003 imp:n=1 vol=73.0420 $ IFE radial fuelled region 2 7.50 - 8.00 cm
2143 253 8.008800000E-02 +2003 +155 -154 -2004 imp:n=1 vol=77.7544 $ IFE radial fuelled region 3 8.00 - 8.50 cm
2144 254 8.009370000E-02 +2004 +155 -154 -2005 imp:n=1 vol=169.6460 $ IFE radial fuelled region 4 8.50 - 9.50 cm
2145 255 8.009930000E-02 +2005 +155 -154 -2006 imp:n=1 vol=188.4960 $ IFE radial fuelled region 5 9.50 - 10.50 cm
2146 256 8.009980000E-02 +2006 +155 -154 -2007 imp:n=1 vol=207.3450 $ IFE radial fuelled region 6 10.50 - 11.50 cm
2147 257 8.009680000E-02 +2007 +155 -154 -2008 imp:n=1 vol=110.7410 $ IFE radial fuelled region 7 11.50 - 12.00 cm
2148 258 8.009330000E-02 +2008 +155 -154 -2009 imp:n=1 vol=139.1100 $ IFE radial fuelled region 8 12.00 - 12.60 cm
c
c Top - Axial Layer 6 (13.0 - 10.0 cm)
2151 261 8.008040000E-02 +2001 +156 -155 -2002 imp:n=1 vol=49.6723 $ IFE radial fuelled region 1 7.14 - 7.50 cm
2152 262 8.008390000E-02 +2002 +156 -155 -2003 imp:n=1 vol=73.0420 $ IFE radial fuelled region 2 7.50 - 8.00 cm
2153 263 8.008800000E-02 +2003 +156 -155 -2004 imp:n=1 vol=77.7544 $ IFE radial fuelled region 3 8.00 - 8.50 cm
2154 264 8.009370000E-02 +2004 +156 -155 -2005 imp:n=1 vol=169.6460 $ IFE radial fuelled region 4 8.50 - 9.50 cm
2155 265 8.009930000E-02 +2005 +156 -155 -2006 imp:n=1 vol=188.4960 $ IFE radial fuelled region 5 9.50 - 10.50 cm
2156 266 8.009980000E-02 +2006 +156 -155 -2007 imp:n=1 vol=207.3450 $ IFE radial fuelled region 6 10.50 - 11.50 cm
2157 267 8.009680000E-02 +2007 +156 -155 -2008 imp:n=1 vol=110.7410 $ IFE radial fuelled region 7 11.50 - 12.00 cm
2158 268 8.009330000E-02 +2008 +156 -155 -2009 imp:n=1 vol=139.1100 $ IFE radial fuelled region 8 12.00 - 12.60 cm
c
c Top - Axial Layer 7 (10.0 - 7.0 cm)
2161 271 8.008040000E-02 +2001 +157 -156 -2002 imp:n=1 vol=49.6723 $ IFE radial fuelled region 1 7.14 - 7.50 cm
2162 272 8.008390000E-02 +2002 +157 -156 -2003 imp:n=1 vol=73.0420 $ IFE radial fuelled region 2 7.50 - 8.00 cm
2163 273 8.008800000E-02 +2003 +157 -156 -2004 imp:n=1 vol=77.7544 $ IFE radial fuelled region 3 8.00 - 8.50 cm
2164 274 8.009370000E-02 +2004 +157 -156 -2005 imp:n=1 vol=169.6460 $ IFE radial fuelled region 4 8.50 - 9.50 cm
2165 275 8.009930000E-02 +2005 +157 -156 -2006 imp:n=1 vol=188.4960 $ IFE radial fuelled region 5 9.50 - 10.50 cm
2166 276 8.009980000E-02 +2006 +157 -156 -2007 imp:n=1 vol=207.3450 $ IFE radial fuelled region 6 10.50 - 11.50 cm

2167 277 8.009680000E-02 +2007 +157 -156 -2008 imp:n=1 vol=110.7410 $ IFE radial fuelled region 7 11.50 - 12.00 cm
2168 278 8.009330000E-02 +2008 +157 -156 -2009 imp:n=1 vol=139.1100 $ IFE radial fuelled region 8 12.00 - 12.60 cm
c
c Top - Axial Layer 8 (7.0 - 4.0 cm)
2171 281 8.008040000E-02 +2001 +158 -157 -2002 imp:n=1 vol=49.6723 $ IFE radial fuelled region 1 7.14 - 7.50 cm
2172 282 8.008390000E-02 +2002 +158 -157 -2003 imp:n=1 vol=73.0420 $ IFE radial fuelled region 2 7.50 - 8.00 cm
2173 283 8.008800000E-02 +2003 +158 -157 -2004 imp:n=1 vol=77.7544 $ IFE radial fuelled region 3 8.00 - 8.50 cm
2174 284 8.009370000E-02 +2004 +158 -157 -2005 imp:n=1 vol=169.6460 $ IFE radial fuelled region 4 8.50 - 9.50 cm
2175 285 8.009930000E-02 +2005 +158 -157 -2006 imp:n=1 vol=188.4960 $ IFE radial fuelled region 5 9.50 - 10.50 cm
2176 286 8.009980000E-02 +2006 +158 -157 -2007 imp:n=1 vol=207.3450 $ IFE radial fuelled region 6 10.50 - 11.50 cm
2177 287 8.009680000E-02 +2007 +158 -157 -2008 imp:n=1 vol=110.7410 $ IFE radial fuelled region 7 11.50 - 12.00 cm
2178 288 8.009330000E-02 +2008 +158 -157 -2009 imp:n=1 vol=139.1100 $ IFE radial fuelled region 8 12.00 - 12.60 cm
c
c Top - Axial Layer 9 (4.0 - 1.0 cm)
2181 291 8.008040000E-02 +2001 +159 -158 -2002 imp:n=1 vol=49.6723 $ IFE radial fuelled region 1 7.14 - 7.50 cm
2182 292 8.008390000E-02 +2002 +159 -158 -2003 imp:n=1 vol=73.0420 $ IFE radial fuelled region 2 7.50 - 8.00 cm
2183 293 8.008800000E-02 +2003 +159 -158 -2004 imp:n=1 vol=77.7544 $ IFE radial fuelled region 3 8.00 - 8.50 cm
2184 294 8.009370000E-02 +2004 +159 -158 -2005 imp:n=1 vol=169.6460 $ IFE radial fuelled region 4 8.50 - 9.50 cm
2185 295 8.009930000E-02 +2005 +159 -158 -2006 imp:n=1 vol=188.4960 $ IFE radial fuelled region 5 9.50 - 10.50 cm
2186 296 8.009980000E-02 +2006 +159 -158 -2007 imp:n=1 vol=207.3450 $ IFE radial fuelled region 6 10.50 - 11.50 cm
2187 297 8.009680000E-02 +2007 +159 -158 -2008 imp:n=1 vol=110.7410 $ IFE radial fuelled region 7 11.50 - 12.00 cm
2188 298 8.009330000E-02 +2008 +159 -158 -2009 imp:n=1 vol=139.1100 $ IFE radial fuelled region 8 12.00 - 12.60 cm
c
c Top - Axial Layer 10 (+1.0 - -1.0 cm)
2191 201 8.008040000E-02 +2001 +161 -159 -2002 imp:n=1 vol=33.1149 $ IFE radial fuelled region 1 7.14 - 7.50 cm
2192 202 8.008390000E-02 +2002 +161 -159 -2003 imp:n=1 vol=48.6947 $ IFE radial fuelled region 2 7.50 - 8.00 cm

```
2193 203 8.008800000E-02   +2003  +161  -159 -2004  imp:n=1  vol=51.8363  $ IFE radial
fuelled region 3   8.00 - 8.50 cm
2194 204 8.009370000E-02   +2004  +161  -159 -2005  imp:n=1  vol=113.0970 $ IFE radial
fuelled region 4   8.50 - 9.50 cm
2195 205 8.009930000E-02   +2005  +161  -159 -2006  imp:n=1  vol=125.6640 $ IFE radial
fuelled region 5   9.50 - 10.50 cm
2196 206 8.009980000E-02   +2006  +161  -159 -2007  imp:n=1  vol=138.2300 $ IFE radial
fuelled region 6   10.50 - 11.50 cm
2197 207 8.009680000E-02   +2007  +161  -159 -2008  imp:n=1  vol=73.8274  $ IFE radial
fuelled region 7   11.50 - 12.00 cm
2198 208 8.009330000E-02   +2008  +161  -159 -2009  imp:n=1  vol=92.7398  $ IFE radial
fuelled region 8   12.00 - 12.60 cm
c
c     Top -  Axial Layer 11  (-1.0  -  -4.0 cm)
2201 291 8.008040000E-02   +2001  +162  -161 -2002  imp:n=1  vol=49.6723  $ IFE radial
fuelled region 1   7.14 - 7.50 cm
2202 292 8.008390000E-02   +2002  +162  -161 -2003  imp:n=1  vol=73.0420  $ IFE radial
fuelled region 2   7.50 - 8.00 cm
2203 293 8.008800000E-02   +2003  +162  -161 -2004  imp:n=1  vol=77.7544  $ IFE radial
fuelled region 3   8.00 - 8.50 cm
2204 294 8.009370000E-02   +2004  +162  -161 -2005  imp:n=1  vol=169.6460 $ IFE radial
fuelled region 4   8.50 - 9.50 cm
2205 295 8.009930000E-02   +2005  +162  -161 -2006  imp:n=1  vol=188.4960 $ IFE radial
fuelled region 5   9.50 - 10.50 cm
2206 296 8.009980000E-02   +2006  +162  -161 -2007  imp:n=1  vol=207.3450 $ IFE radial
fuelled region 6   10.50 - 11.50 cm
2207 297 8.009680000E-02   +2007  +162  -161 -2008  imp:n=1  vol=110.7410 $ IFE radial
fuelled region 7   11.50 - 12.00 cm
2208 298 8.009330000E-02   +2008  +162  -161 -2009  imp:n=1  vol=139.1100 $ IFE radial
fuelled region 8   12.00 - 12.60 cm
c
c     Top -  Axial Layer 12  (-4.0   -  7.0 cm)
2211 281 8.008040000E-02   +2001  +163  -162 -2002  imp:n=1  vol=49.6723  $ IFE radial
fuelled region 1   7.14 - 7.50 cm
2212 282 8.008390000E-02   +2002  +163  -162 -2003  imp:n=1  vol=73.0420  $ IFE radial
fuelled region 2   7.50 - 8.00 cm
2213 283 8.008800000E-02   +2003  +163  -162 -2004  imp:n=1  vol=77.7544  $ IFE radial
fuelled region 3   8.00 - 8.50 cm
2214 284 8.009370000E-02   +2004  +163  -162 -2005  imp:n=1  vol=169.6460 $ IFE radial
fuelled region 4   8.50 - 9.50 cm
2215 285 8.009930000E-02   +2005  +163  -162 -2006  imp:n=1  vol=188.4960 $ IFE radial
fuelled region 5   9.50 - 10.50 cm
2216 286 8.009980000E-02   +2006  +163  -162 -2007  imp:n=1  vol=207.3450 $ IFE radial
fuelled region 6   10.50 - 11.50 cm
2217 287 8.009680000E-02   +2007  +163  -162 -2008  imp:n=1  vol=110.7410 $ IFE radial
fuelled region 7   11.50 - 12.00 cm
```

2218 288 8.009330000E-02   +2008 +163 -162 -2009 imp:n=1 vol=139.1100 $ IFE radial fuelled region 8   12.00 - 12.60 cm
c
c   Top - Axial Layer 13 (-7.0   -   -10.0 cm)
2221 271 8.008040000E-02   +2001 +164 -163 -2002 imp:n=1 vol=49.6723 $ IFE radial fuelled region 1   7.14 - 7.50 cm
2222 272 8.008390000E-02   +2002 +164 -163 -2003 imp:n=1 vol=73.0420 $ IFE radial fuelled region 2   7.50 - 8.00 cm
2223 273 8.008800000E-02   +2003 +164 -163 -2004 imp:n=1 vol=77.7544 $ IFE radial fuelled region 3   8.00 - 8.50 cm
2224 274 8.009370000E-02   +2004 +164 -163 -2005 imp:n=1 vol=169.6460 $ IFE radial fuelled region 4   8.50 - 9.50 cm
2225 275 8.009930000E-02   +2005 +164 -163 -2006 imp:n=1 vol=188.4960 $ IFE radial fuelled region 5   9.50 - 10.50 cm
2226 276 8.009980000E-02   +2006 +164 -163 -2007 imp:n=1 vol=207.3450 $ IFE radial fuelled region 6   10.50 - 11.50 cm
2227 277 8.009680000E-02   +2007 +164 -163 -2008 imp:n=1 vol=110.7410 $ IFE radial fuelled region 7   11.50 - 12.00 cm
2228 278 8.009330000E-02   +2008 +164 -163 -2009 imp:n=1 vol=139.1100 $ IFE radial fuelled region 8   12.00 - 12.60 cm
c
c   Top - Axial Layer 14 (-10.0 -   -13.0 cm)
2231 261 8.008040000E-02   +2001 +165 -164 -2002 imp:n=1 vol=49.6723 $ IFE radial fuelled region 1   7.14 - 7.50 cm
2232 262 8.008390000E-02   +2002 +165 -164 -2003 imp:n=1 vol=73.0420 $ IFE radial fuelled region 2   7.50 - 8.00 cm
2233 263 8.008800000E-02   +2003 +165 -164 -2004 imp:n=1 vol=77.7544 $ IFE radial fuelled region 3   8.00 - 8.50 cm
2234 264 8.009370000E-02   +2004 +165 -164 -2005 imp:n=1 vol=169.6460 $ IFE radial fuelled region 4   8.50 - 9.50 cm
2235 265 8.009930000E-02   +2005 +165 -164 -2006 imp:n=1 vol=188.4960 $ IFE radial fuelled region 5   9.50 - 10.50 cm
2236 266 8.009980000E-02   +2006 +165 -164 -2007 imp:n=1 vol=207.3450 $ IFE radial fuelled region 6   10.50 - 11.50 cm
2237 267 8.009680000E-02   +2007 +165 -164 -2008 imp:n=1 vol=110.7410 $ IFE radial fuelled region 7   11.50 - 12.00 cm
2238 268 8.009330000E-02   +2008 +165 -164 -2009 imp:n=1 vol=139.1100 $ IFE radial fuelled region 8   12.00 - 12.60 cm
c
c   Top - Axial Layer 15 (-13.0 - -16.0 cm)
2241 251 8.008040000E-02   +2001 +166 -165 -2002 imp:n=1 vol=49.6723 $ IFE radial fuelled region 1   7.14 - 7.50 cm
2242 252 8.008390000E-02   +2002 +166 -165 -2003 imp:n=1 vol=73.0420 $ IFE radial fuelled region 2   7.50 - 8.00 cm
2243 253 8.008800000E-02   +2003 +166 -165 -2004 imp:n=1 vol=77.7544 $ IFE radial fuelled region 3   8.00 - 8.50 cm

2244 254 8.009370000E-02 +2004 +166 -165 -2005 imp:n=1 vol=169.6460 $ IFE radial fuelled region 4 8.50 - 9.50 cm
2245 255 8.009930000E-02 +2005 +166 -165 -2006 imp:n=1 vol=188.4960 $ IFE radial fuelled region 5 9.50 - 10.50 cm
2246 256 8.009980000E-02 +2006 +166 -165 -2007 imp:n=1 vol=207.3450 $ IFE radial fuelled region 6 10.50 - 11.50 cm
2247 257 8.009680000E-02 +2007 +166 -165 -2008 imp:n=1 vol=110.7410 $ IFE radial fuelled region 7 11.50 - 12.00 cm
2248 258 8.009330000E-02 +2008 +166 -165 -2009 imp:n=1 vol=139.1100 $ IFE radial fuelled region 8 12.00 - 12.60 cm
c
c Top - Axial Layer 16 (-16.0 - -19.0 cm)
2251 241 8.008040000E-02 +2001 +167 -166 -2002 imp:n=1 vol=49.6723 $ IFE radial fuelled region 1 7.14 - 7.50 cm
2252 242 8.008390000E-02 +2002 +167 -166 -2003 imp:n=1 vol=73.0420 $ IFE radial fuelled region 2 7.50 - 8.00 cm
2253 243 8.008800000E-02 +2003 +167 -166 -2004 imp:n=1 vol=77.7544 $ IFE radial fuelled region 3 8.00 - 8.50 cm
2254 244 8.009370000E-02 +2004 +167 -166 -2005 imp:n=1 vol=169.6460 $ IFE radial fuelled region 4 8.50 - 9.50 cm
2255 245 8.009930000E-02 +2005 +167 -166 -2006 imp:n=1 vol=188.4960 $ IFE radial fuelled region 5 9.50 - 10.50 cm
2256 246 8.009980000E-02 +2006 +167 -166 -2007 imp:n=1 vol=207.3450 $ IFE radial fuelled region 6 10.50 - 11.50 cm
2257 247 8.009680000E-02 +2007 +167 -166 -2008 imp:n=1 vol=110.7410 $ IFE radial fuelled region 7 11.50 - 12.00 cm
2258 248 8.009330000E-02 +2008 +167 -166 -2009 imp:n=1 vol=139.1100 $ IFE radial fuelled region 8 12.00 - 12.60 cm
c
c Top - Axial Layer 17 (-19.0 - 22.0 cm)
2261 231 8.008040000E-02 +2001 +168 -167 -2002 imp:n=1 vol=49.6723 $ IFE radial fuelled region 1 7.14 - 7.50 cm
2262 232 8.008390000E-02 +2002 +168 -167 -2003 imp:n=1 vol=73.0420 $ IFE radial fuelled region 2 7.50 - 8.00 cm
2263 233 8.008800000E-02 +2003 +168 -167 -2004 imp:n=1 vol=77.7544 $ IFE radial fuelled region 3 8.00 - 8.50 cm
2264 234 8.009370000E-02 +2004 +168 -167 -2005 imp:n=1 vol=169.6460 $ IFE radial fuelled region 4 8.50 - 9.50 cm
2265 235 8.009930000E-02 +2005 +168 -167 -2006 imp:n=1 vol=188.4960 $ IFE radial fuelled region 5 9.50 - 10.50 cm
2266 236 8.009980000E-02 +2006 +168 -167 -2007 imp:n=1 vol=207.3450 $ IFE radial fuelled region 6 10.50 - 11.50 cm
2267 237 8.009680000E-02 +2007 +168 -167 -2008 imp:n=1 vol=110.7410 $ IFE radial fuelled region 7 11.50 - 12.00 cm
2268 238 8.009330000E-02 +2008 +168 -167 -2009 imp:n=1 vol=139.1100 $ IFE radial fuelled region 8 12.00 - 12.60 cm

```
c
c     Top -  Axial Layer 18  (-22.0  - 25.0 cm)
2271 221 8.008040000E-02   +2001  +169  -168 -2002  imp:n=1  vol=49.6723  $ IFE radial
fuelled region 1   7.14 - 7.50 cm
2272 222 8.008390000E-02   +2002  +169  -168 -2003  imp:n=1  vol=73.0420  $ IFE radial
fuelled region 2   7.50 - 8.00 cm
2273 223 8.008800000E-02   +2003  +169  -168 -2004  imp:n=1  vol=77.7544  $ IFE radial
fuelled region 3   8.00 - 8.50 cm
2274 224 8.009370000E-02   +2004  +169  -168 -2005  imp:n=1  vol=169.6460 $ IFE radial
fuelled region 4   8.50 - 9.50 cm
2275 225 8.009930000E-02   +2005  +169  -168 -2006  imp:n=1  vol=188.4960 $ IFE radial
fuelled region 5   9.50 - 10.50 cm
2276 226 8.009980000E-02   +2006  +169  -168 -2007  imp:n=1  vol=207.3450 $ IFE radial
fuelled region 6   10.50 - 11.50 cm
2277 227 8.009680000E-02   +2007  +169  -168 -2008  imp:n=1  vol=110.7410 $ IFE radial
fuelled region 7   11.50 - 12.00 cm
2278 228 8.009330000E-02   +2008  +169  -168 -2009  imp:n=1  vol=139.1100 $ IFE radial
fuelled region 8   12.00 - 12.60 cm
c
c     Top -  Axial Layer 19  (-25.0  -  -25.4 cm)
2281 211 8.008040000E-02   +2001  +200  -169 -2002  imp:n=1  vol=6.6230  $ IFE radial
fuelled region 1   7.14 - 7.50 cm
2282 212 8.008390000E-02   +2002  +200  -169 -2003  imp:n=1  vol=9.7389  $ IFE radial
fuelled region 2   7.50 - 8.00 cm
2283 213 8.008800000E-02   +2003  +200  -169 -2004  imp:n=1  vol=10.3673 $ IFE radial
fuelled region 3   8.00 - 8.50 cm
2284 214 8.009370000E-02   +2004  +200  -169 -2005  imp:n=1  vol=22.6195 $ IFE radial
fuelled region 4   8.50 - 9.50 cm
2285 215 8.009930000E-02   +2005  +200  -169 -2006  imp:n=1  vol=25.1327 $ IFE radial
fuelled region 5   9.50 - 10.50 cm
2286 216 8.009980000E-02   +2006  +200  -169 -2007  imp:n=1  vol=27.6460 $ IFE radial
fuelled region 6   10.50 - 11.50 cm
2287 217 8.009680000E-02   +2007  +200  -169 -2008  imp:n=1  vol=14.7655 $ IFE radial
fuelled region 7   11.50 - 12.00 cm
2288 218 8.009330000E-02   +2008  +200  -169 -2009  imp:n=1  vol=18.5480 $ IFE radial
fuelled region 8   12.00 - 12.60 cm
c
c
2199  200 8.01309E-02   +2009  +200  -100 -2010  imp:n=1  vol=921.1590 $inner unfuelled
region
2200  20  6.02083E-02   +2010  +200  -100 -2200  imp:n=1   $IFE outer sidewall
c
c
2600  70  8.01308E-02   +2000  +100  -101 -2010  imp:n=1   $ IFE unfuelled - upper region
2601  3   1.00053E-01   +2000  +101  -199 -2010  imp:n=1   $ water above IFE upper region
2602  71  7.96002E-02   +2000  +201  -200 -2010  imp:n=1   $ IFE unfuelled - lower region
```

```
2603  1   9.89921E-02   +2000  +299  -201 -2010  imp:n=1   $ water below IFE upper region
c
2620  20  6.02083E-02   +2010  +202  -200 -2201  imp:n=1   $ IFE outer sidewall lower
extension
2622   1  9.89921E-02   +2010  +299  -202 -2201  imp:n=1   $ water below IFE outer
sidewall lower extension
c
2624  2   9.95227E-02   -2201  +200  -100 +2200  imp:n=1   $ water between fuel elements--
active fuel region
c
2630  20  6.02083E-02   +2010  +100  -102 -2201  imp:n=1   $ IFE outer sidewall upper
extension
2632   3  1.00053E-01   +2010  -199  +102 -2201  imp:n=1   $ water above IFE outer
sidewall outer extension
c
2640  20  6.02083E-02   +1999  -200  +299 -2000  imp:n=1   $ IFE inner sidewall-lower core
support
c
2650  20  6.02083E-02   +1999  +100  -199 -2000  imp:n=1   $ IFE inner sidewall-upper core
support
c
c
c          ----------------------------------------
c                         Region III
c
c                  OUTER FUEL ELEMENT (OFE)
c          ----------------------------------------
c
c  The outer fuel element is region-3
c  The outer fuel element (OFE) consists of 369 fuel plates arranged in an
c    involutes shape. Each plate contains 18.44g +-1% of U-235.
c  The OFE fueled area is modeled by by homogenizing the uranium, aluminum
c    and water, in 9 radial fueled regions that reflect the different  U-235
c    concentrations in each fuel plate. The OFE is divided into 171 cells,
c    9 radial fueled regions and 19 axial fueled layers
c
c   --------------------
c     OEF Cell Cards
C   --------------------
c
c
2300  20  6.02083E-02   +2201  +200  -100 -2300   imp:n=1   $OFE inner sidewall
2400  200 8.01309E-02   +2300  +200  -100 -2301   imp:n=1  vol=1010.9800  $outer
unfuelled region
c
c
```

c   Top - Axial Layer 1   (25.4 - 25.0 cm)
2401 311 8.005830000E-02   +2301 +150 -100 -2302 imp:n=1 vol=14.2602 $ OFE radial fuelled region 1   15.12951 - 15.5 cm
2402 312 8.008950000E-02   +2302 +150 -100 -2303 imp:n=1 vol=19.7920 $ OFE radial fuelled region 2   15.5 - 16.0 cm
2403 313 8.012280000E-02   +2303 +150 -100 -2304 imp:n=1 vol=20.4204 $ OFE radial fuelled region 3   16.0 - 16.5 cm
2404 314 8.015300000E-02   +2304 +150 -100 -2305 imp:n=1 vol=42.7257 $ OFE radial fuelled region 4   16.5 - 17.5 cm
2405 315 8.014370000E-02   +2305 +150 -100 -2306 imp:n=1 vol=45.2389 $ OFE radial fuelled region 5   17.5 - 18.5 cm
2406 316 8.009850000E-02   +2306 +150 -100 -2307 imp:n=1 vol=47.7522 $ OFE radial fuelled region 6   18.5 - 19.5 cm
2407 317 8.005550000E-02   +2307 +150 -100 -2308 imp:n=1 vol=24.8186 $ OFE radial fuelled region 7   19.5 - 20.0 cm
2408 318 8.002710000E-02   +2308 +150 -100 -2309 imp:n=1 vol=25.4469 $ OFE radial fuelled region 8   20.0 - 20.5 cm
2409 319 8.000130000E-02   +2309 +150 -100 -2310 imp:n=1 vol=24.9147 $ OFE radial fuelled region 9   20.5 - 20.978 cm
c
c   Top - Axial Layer 2   (25.0 - 22.0 cm)
2411 321 8.005830000E-02   +2301 +151 -150 -2302 imp:n=1 vol=106.9520 $ OFE radial fuelled region 1   15.12951 - 15.5 cm
2412 322 8.008950000E-02   +2302 +151 -150 -2303 imp:n=1 vol=148.4400 $ OFE radial fuelled region 2   15.5 - 16.0 cm
2413 323 8.012280000E-02   +2303 +151 -150 -2304 imp:n=1 vol=153.1530 $ OFE radial fuelled region 3   16.0 - 16.5 cm
2414 324 8.015300000E-02   +2304 +151 -150 -2305 imp:n=1 vol=320.4420 $ OFE radial fuelled region 4   16.5 - 17.5 cm
2415 325 8.014370000E-02   +2305 +151 -150 -2306 imp:n=1 vol=339.2920 $ OFE radial fuelled region 5   17.5 - 18.5 cm
2416 326 8.009850000E-02   +2306 +151 -150 -2307 imp:n=1 vol=358.1420 $ OFE radial fuelled region 6   18.5 - 19.5 cm
2417 327 8.005550000E-02   +2307 +151 -150 -2308 imp:n=1 vol=186.1390 $ OFE radial fuelled region 7   19.5 - 20.0 cm
2418 328 8.002710000E-02   +2308 +151 -150 -2309 imp:n=1 vol=190.8520 $ OFE radial fuelled region 8   20.0 - 20.5 cm
2419 329 8.000130000E-02   +2309 +151 -150 -2310 imp:n=1 vol=186.8600 $ OFE radial fuelled region 9   20.5 - 20.978 cm
c
c   Top - Axial Layer 3   (22.0 - 19.0 cm)
2421 331 8.005830000E-02   +2301 +153 -151 -2302 imp:n=1 vol=106.9520 $ OFE radial fuelled region 1   15.12951 - 15.5 cm
2422 332 8.008950000E-02   +2302 +153 -151 -2303 imp:n=1 vol=148.4400 $ OFE radial fuelled region 2   15.5 - 16.0 cm

2423 333 8.012280000E-02 +2303 +153 -151 -2304 imp:n=1 vol=153.1530 $ OFE radial fuelled region 3 16.0 - 16.5 cm
2424 334 8.015300000E-02 +2304 +153 -151 -2305 imp:n=1 vol=320.4420 $ OFE radial fuelled region 4 16.5 - 17.5 cm
2425 335 8.014370000E-02 +2305 +153 -151 -2306 imp:n=1 vol=339.2920 $ OFE radial fuelled region 5 17.5 - 18.5 cm
2426 336 8.009850000E-02 +2306 +153 -151 -2307 imp:n=1 vol=358.1420 $ OFE radial fuelled region 6 18.5 - 19.5 cm
2427 337 8.005550000E-02 +2307 +153 -151 -2308 imp:n=1 vol=186.1390 $ OFE radial fuelled region 7 19.5 - 20.0 cm
2428 338 8.002710000E-02 +2308 +153 -151 -2309 imp:n=1 vol=190.8520 $ OFE radial fuelled region 8 20.0 - 20.5 cm
2429 339 8.000130000E-02 +2309 +153 -151 -2310 imp:n=1 vol=186.8600 $ OFE radial fuelled region 9 20.5 - 20.978 cm
c
c Top - Axial Layer 4 (19.0 - 16.0 cm)
2431 341 8.005830000E-02 +2301 +154 -153 -2302 imp:n=1 vol=106.9520 $ OFE radial fuelled region 1 15.12951 - 15.5 cm
2432 342 8.008950000E-02 +2302 +154 -153 -2303 imp:n=1 vol=148.4400 $ OFE radial fuelled region 2 15.5 - 16.0 cm
2433 343 8.012280000E-02 +2303 +154 -153 -2304 imp:n=1 vol=153.1530 $ OFE radial fuelled region 3 16.0 - 16.5 cm
2434 344 8.015300000E-02 +2304 +154 -153 -2305 imp:n=1 vol=320.4420 $ OFE radial fuelled region 4 16.5 - 17.5 cm
2435 345 8.014370000E-02 +2305 +154 -153 -2306 imp:n=1 vol=339.2920 $ OFE radial fuelled region 5 17.5 - 18.5 cm
2436 346 8.009850000E-02 +2306 +154 -153 -2307 imp:n=1 vol=358.1420 $ OFE radial fuelled region 6 18.5 - 19.5 cm
2437 347 8.005550000E-02 +2307 +154 -153 -2308 imp:n=1 vol=186.1390 $ OFE radial fuelled region 7 19.5 - 20.0 cm
2438 348 8.002710000E-02 +2308 +154 -153 -2309 imp:n=1 vol=190.8520 $ OFE radial fuelled region 8 20.0 - 20.5 cm
2439 349 8.000130000E-02 +2309 +154 -153 -2310 imp:n=1 vol=186.8600 $ OFE radial fuelled region 9 20.5 - 20.978 cm
c
c Top - Axial Layer 5 (16.0 - 13.0 cm)
2441 351 8.005830000E-02 +2301 +155 -154 -2302 imp:n=1 vol=106.9520 $ OFE radial fuelled region 1 15.12951 - 15.5 cm
2442 352 8.008950000E-02 +2302 +155 -154 -2303 imp:n=1 vol=148.4400 $ OFE radial fuelled region 2 15.5 - 16.0 cm
2443 353 8.012280000E-02 +2303 +155 -154 -2304 imp:n=1 vol=153.1530 $ OFE radial fuelled region 3 16.0 - 16.5 cm
2444 354 8.015300000E-02 +2304 +155 -154 -2305 imp:n=1 vol=320.4420 $ OFE radial fuelled region 4 16.5 - 17.5 cm
2445 355 8.014370000E-02 +2305 +155 -154 -2306 imp:n=1 vol=339.2920 $ OFE radial fuelled region 5 17.5 - 18.5 cm

2446 356 8.009850000E-02   +2306 +155 -154 -2307 imp:n=1 vol=358.1420 $ OFE radial fuelled region 6   18.5 - 19.5 cm
2447 357 8.005550000E-02   +2307 +155 -154 -2308 imp:n=1 vol=186.1390 $ OFE radial fuelled region 7   19.5 - 20.0 cm
2448 358 8.002710000E-02   +2308 +155 -154 -2309 imp:n=1 vol=190.8520 $ OFE radial fuelled region 8   20.0 - 20.5 cm
2449 359 8.000130000E-02   +2309 +155 -154 -2310 imp:n=1 vol=186.8600 $ OFE radial fuelled region 9   20.5 - 20.978 cm
c
c   Top - Axial Layer 6   (13.0 - 10.0 cm)
2451 361 8.005830000E-02   +2301 +156 -155 -2302 imp:n=1 vol=106.9520 $ OFE radial fuelled region 1   15.12951 - 15.5 cm
2452 362 8.008950000E-02   +2302 +156 -155 -2303 imp:n=1 vol=148.4400 $ OFE radial fuelled region 2   15.5 - 16.0 cm
2453 363 8.012280000E-02   +2303 +156 -155 -2304 imp:n=1 vol=153.1530 $ OFE radial fuelled region 3   16.0 - 16.5 cm
2454 364 8.015300000E-02   +2304 +156 -155 -2305 imp:n=1 vol=320.4420 $ OFE radial fuelled region 4   16.5 - 17.5 cm
2455 365 8.014370000E-02   +2305 +156 -155 -2306 imp:n=1 vol=339.2920 $ OFE radial fuelled region 5   17.5 - 18.5 cm
2456 366 8.009850000E-02   +2306 +156 -155 -2307 imp:n=1 vol=358.1420 $ OFE radial fuelled region 6   18.5 - 19.5 cm
2457 367 8.005550000E-02   +2307 +156 -155 -2308 imp:n=1 vol=186.1390 $ OFE radial fuelled region 7   19.5 - 20.0 cm
2458 368 8.002710000E-02   +2308 +156 -155 -2309 imp:n=1 vol=190.8520 $ OFE radial fuelled region 8   20.0 - 20.5 cm
2459 369 8.000130000E-02   +2309 +156 -155 -2310 imp:n=1 vol=186.8600 $ OFE radial fuelled region 9   20.5 - 20.978 cm
c
c   Top - Axial Layer 7   (10.0 - 7.0 cm)
2461 371 8.005830000E-02   +2301 +157 -156 -2302 imp:n=1 vol=106.9520 $ OFE radial fuelled region 1   15.12951 - 15.5 cm
2462 372 8.008950000E-02   +2302 +157 -156 -2303 imp:n=1 vol=148.4400 $ OFE radial fuelled region 2   15.5 - 16.0 cm
2463 373 8.012280000E-02   +2303 +157 -156 -2304 imp:n=1 vol=153.1530 $ OFE radial fuelled region 3   16.0 - 16.5 cm
2464 374 8.015300000E-02   +2304 +157 -156 -2305 imp:n=1 vol=320.4420 $ OFE radial fuelled region 4   16.5 - 17.5 cm
2465 375 8.014370000E-02   +2305 +157 -156 -2306 imp:n=1 vol=339.2920 $ OFE radial fuelled region 5   17.5 - 18.5 cm
2466 376 8.009850000E-02   +2306 +157 -156 -2307 imp:n=1 vol=358.1420 $ OFE radial fuelled region 6   18.5 - 19.5 cm
2467 377 8.005550000E-02   +2307 +157 -156 -2308 imp:n=1 vol=186.1390 $ OFE radial fuelled region 7   19.5 - 20.0 cm
2468 378 8.002710000E-02   +2308 +157 -156 -2309 imp:n=1 vol=190.8520 $ OFE radial fuelled region 8   20.0 - 20.5 cm

```
2469 379 8.000130000E-02    +2309  +157  -156 -2310  imp:n=1  vol=186.8600 $  OFE
radial fuelled region 9   20.5 - 20.978 cm
c
c     Top - Axial  Layer 8    (7.0  - 4.0 cm)
2471 381 8.005830000E-02    +2301  +158  -157 -2302  imp:n=1  vol=106.9520 $  OFE
radial fuelled region 1   15.12951 - 15.5 cm
2472 382 8.008950000E-02    +2302  +158  -157 -2303  imp:n=1  vol=148.4400 $  OFE
radial fuelled region 2   15.5 - 16.0 cm
2473 383 8.012280000E-02    +2303  +158  -157 -2304  imp:n=1  vol=153.1530 $  OFE
radial fuelled region 3   16.0 - 16.5 cm
2474 384 8.015300000E-02    +2304  +158  -157 -2305  imp:n=1  vol=320.4420 $  OFE
radial fuelled region 4   16.5 - 17.5 cm
2475 385 8.014370000E-02    +2305  +158  -157 -2306  imp:n=1  vol=339.2920 $  OFE
radial fuelled region 5   17.5 - 18.5 cm
2476 386 8.009850000E-02    +2306  +158  -157 -2307  imp:n=1  vol=358.1420 $  OFE
radial fuelled region 6   18.5 - 19.5 cm
2477 387 8.005550000E-02    +2307  +158  -157 -2308  imp:n=1  vol=186.1390 $  OFE
radial fuelled region 7   19.5 - 20.0 cm
2478 388 8.002710000E-02    +2308  +158  -157 -2309  imp:n=1  vol=190.8520 $  OFE
radial fuelled region 8   20.0 - 20.5 cm
2479 389 8.000130000E-02    +2309  +158  -157 -2310  imp:n=1  vol=186.8600 $  OFE
radial fuelled region 9   20.5 - 20.978 cm
c
c     Top - Axial  Layer 9    (4.0  - 1.0 cm)
2481 391 8.005830000E-02    +2301  +159  -158 -2302  imp:n=1  vol=106.9520 $  OFE
radial fuelled region 1   15.12951 - 15.5 cm
2482 392 8.008950000E-02    +2302  +159  -158 -2303  imp:n=1  vol=148.4400 $  OFE
radial fuelled region 2   15.5 - 16.0 cm
2483 393 8.012280000E-02    +2303  +159  -158 -2304  imp:n=1  vol=153.1530 $  OFE
radial fuelled region 3   16.0 - 16.5 cm
2484 394 8.015300000E-02    +2304  +159  -158 -2305  imp:n=1  vol=320.4420 $  OFE
radial fuelled region 4   16.5 - 17.5 cm
2485 395 8.014370000E-02    +2305  +159  -158 -2306  imp:n=1  vol=339.2920 $  OFE
radial fuelled region 5   17.5 - 18.5 cm
2486 396 8.009850000E-02    +2306  +159  -158 -2307  imp:n=1  vol=358.1420 $  OFE
radial fuelled region 6   18.5 - 19.5 cm
2487 397 8.005550000E-02    +2307  +159  -158 -2308  imp:n=1  vol=186.1390 $  OFE
radial fuelled region 7   19.5 - 20.0 cm
2488 398 8.002710000E-02    +2308  +159  -158 -2309  imp:n=1  vol=190.8520 $  OFE
radial fuelled region 8   20.0 - 20.5 cm
2489 399 8.000130000E-02    +2309  +159  -158 -2310  imp:n=1  vol=186.8600 $  OFE
radial fuelled region 9   20.5 - 20.978 cm
c
c     Top - Axial  Layer 10    (1.0  - 1.0 cm)
2491 301 8.005830000E-02    +2301  +161  -159 -2302  imp:n=1  vol=71.3011  $  OFE
radial fuelled region 1   15.12951 - 15.5 cm
```

2492 302 8.008950000E-02 +2302 +161 -159 -2303 imp:n=1 vol=98.9602 $ OFE radial fuelled region 2 15.5 - 16.0 cm
2493 303 8.012280000E-02 +2303 +161 -159 -2304 imp:n=1 vol=102.1020 $ OFE radial fuelled region 3 16.0 - 16.5 cm
2494 304 8.015300000E-02 +2304 +161 -159 -2305 imp:n=1 vol=213.6280 $ OFE radial fuelled region 4 16.5 - 17.5 cm
2495 305 8.014370000E-02 +2305 +161 -159 -2306 imp:n=1 vol=226.1950 $ OFE radial fuelled region 5 17.5 - 18.5 cm
2496 306 8.009850000E-02 +2306 +161 -159 -2307 imp:n=1 vol=238.7610 $ OFE radial fuelled region 6 18.5 - 19.5 cm
2497 307 8.005550000E-02 +2307 +161 -159 -2308 imp:n=1 vol=124.0930 $ OFE radial fuelled region 7 19.5 - 20.0 cm
2498 308 8.002710000E-02 +2308 +161 -159 -2309 imp:n=1 vol=127.2350 $ OFE radial fuelled region 8 20.0 - 20.5 cm
2499 309 8.000130000E-02 +2309 +161 -159 -2310 imp:n=1 vol=124.5730 $ OFE radial fuelled region 9 20.5 - 20.978 cm
c
c 8Top - Axial Layer 11 (-1.0 - -4.0 cm)
2501 391 8.005830000E-02 +2301 +162 -161 -2302 imp:n=1 vol=106.9520 $ OFE radial fuelled region 1 15.12951 - 15.5 cm
2502 392 8.008950000E-02 +2302 +162 -161 -2303 imp:n=1 vol=148.4400 $ OFE radial fuelled region 2 15.5 - 16.0 cm
2503 393 8.012280000E-02 +2303 +162 -161 -2304 imp:n=1 vol=153.1530 $ OFE radial fuelled region 3 16.0 - 16.5 cm
2504 394 8.015300000E-02 +2304 +162 -161 -2305 imp:n=1 vol=320.4420 $ OFE radial fuelled region 4 16.5 - 17.5 cm
2505 395 8.014370000E-02 +2305 +162 -161 -2306 imp:n=1 vol=339.2920 $ OFE radial fuelled region 5 17.5 - 18.5 cm
2506 396 8.009850000E-02 +2306 +162 -161 -2307 imp:n=1 vol=358.1420 $ OFE radial fuelled region 6 18.5 - 19.5 cm
2507 397 8.005550000E-02 +2307 +162 -161 -2308 imp:n=1 vol=186.1390 $ OFE radial fuelled region 7 19.5 - 20.0 cm
2508 398 8.002710000E-02 +2308 +162 -161 -2309 imp:n=1 vol=190.8520 $ OFE radial fuelled region 8 20.0 - 20.5 cm
2509 399 8.000130000E-02 +2309 +162 -161 -2310 imp:n=1 vol=186.8600 $ OFE radial fuelled region 9 20.5 - 20.978 cm
c
c Top - Axial Layer 12 (-4.0 - -7.0 cm)
2511 381 8.005830000E-02 +2301 +163 -162 -2302 imp:n=1 vol=106.9520 $ OFE radial fuelled region 1 15.12951 - 15.5 cm
2512 382 8.008950000E-02 +2302 +163 -162 -2303 imp:n=1 vol=148.4400 $ OFE radial fuelled region 2 15.5 - 16.0 cm
2513 383 8.012280000E-02 +2303 +163 -162 -2304 imp:n=1 vol=153.1530 $ OFE radial fuelled region 3 16.0 - 16.5 cm
2514 384 8.015300000E-02 +2304 +163 -162 -2305 imp:n=1 vol=320.4420 $ OFE radial fuelled region 4 16.5 - 17.5 cm

2515 385 8.014370000E-02   +2305 +163 -162 -2306 imp:n=1 vol=339.2920 $ OFE radial fuelled region 5   17.5 - 18.5 cm
2516 386 8.009850000E-02   +2306 +163 -162 -2307 imp:n=1 vol=358.1420 $ OFE radial fuelled region 6   18.5 - 19.5 cm
2517 387 8.005550000E-02   +2307 +163 -162 -2308 imp:n=1 vol=186.1390 $ OFE radial fuelled region 7   19.5 - 20.0 cm
2518 388 8.002710000E-02   +2308 +163 -162 -2309 imp:n=1 vol=190.8520 $ OFE radial fuelled region 8   20.0 - 20.5 cm
2519 389 8.000130000E-02   +2309 +163 -162 -2310 imp:n=1 vol=186.8600 $ OFE radial fuelled region 9   20.5 - 20.978 cm
c
c   Top - Axial Layer 13   (-7.0 - -10.0 cm)
2521 371 8.005830000E-02   +2301 +164 -163 -2302 imp:n=1 vol=106.9520 $ OFE radial fuelled region 1   15.12951 - 15.5 cm
2522 372 8.008950000E-02   +2302 +164 -163 -2303 imp:n=1 vol=148.4400 $ OFE radial fuelled region 2   15.5 - 16.0 cm
2523 373 8.012280000E-02   +2303 +164 -163 -2304 imp:n=1 vol=153.1530 $ OFE radial fuelled region 3   16.0 - 16.5 cm
2524 374 8.015300000E-02   +2304 +164 -163 -2305 imp:n=1 vol=320.4420 $ OFE radial fuelled region 4   16.5 - 17.5 cm
2525 375 8.014370000E-02   +2305 +164 -163 -2306 imp:n=1 vol=339.2920 $ OFE radial fuelled region 5   17.5 - 18.5 cm
2526 376 8.009850000E-02   +2306 +164 -163 -2307 imp:n=1 vol=358.1420 $ OFE radial fuelled region 6   18.5 - 19.5 cm
2527 377 8.005550000E-02   +2307 +164 -163 -2308 imp:n=1 vol=186.1390 $ OFE radial fuelled region 7   19.5 - 20.0 cm
2528 378 8.002710000E-02   +2308 +164 -163 -2309 imp:n=1 vol=190.8520 $ OFE radial fuelled region 8   20.0 - 20.5 cm
2529 379 8.000130000E-02   +2309 +164 -163 -2310 imp:n=1 vol=186.8600 $ OFE radial fuelled region 9   20.5 - 20.978 cm
c
c   Top - Axial Layer 14   (-10.0 - -13.0 cm)
2531 361 8.005830000E-02   +2301 +165 -164 -2302 imp:n=1 vol=106.9520 $ OFE radial fuelled region 1   15.12951 - 15.5 cm
2532 362 8.008950000E-02   +2302 +165 -164 -2303 imp:n=1 vol=148.4400 $ OFE radial fuelled region 2   15.5 - 16.0 cm
2533 363 8.012280000E-02   +2303 +165 -164 -2304 imp:n=1 vol=153.1530 $ OFE radial fuelled region 3   16.0 - 16.5 cm
2534 364 8.015300000E-02   +2304 +165 -164 -2305 imp:n=1 vol=320.4420 $ OFE radial fuelled region 4   16.5 - 17.5 cm
2535 365 8.014370000E-02   +2305 +165 -164 -2306 imp:n=1 vol=339.2920 $ OFE radial fuelled region 5   17.5 - 18.5 cm
2536 366 8.009850000E-02   +2306 +165 -164 -2307 imp:n=1 vol=358.1420 $ OFE radial fuelled region 6   18.5 - 19.5 cm
2537 367 8.005550000E-02   +2307 +165 -164 -2308 imp:n=1 vol=186.1390 $ OFE radial fuelled region 7   19.5 - 20.0 cm

2538 368 8.002710000E-02   +2308 +165 -164 -2309 imp:n=1 vol=190.8520 $ OFE radial fuelled region 8   20.0 - 20.5 cm
2539 369 8.000130000E-02   +2309 +165 -164 -2310 imp:n=1 vol=186.8600 $ OFE radial fuelled region 9   20.5 - 20.978 cm
c
c   Top - Axial Layer 15   (-13.0 - -16.0 cm)
2541 351 8.005830000E-02   +2301 +166 -165 -2302 imp:n=1 vol=106.9520 $ OFE radial fuelled region 1   15.12951 - 15.5 cm
2542 352 8.008950000E-02   +2302 +166 -165 -2303 imp:n=1 vol=148.4400 $ OFE radial fuelled region 2   15.5 - 16.0 cm
2543 353 8.012280000E-02   +2303 +166 -165 -2304 imp:n=1 vol=153.1530 $ OFE radial fuelled region 3   16.0 - 16.5 cm
2544 354 8.015300000E-02   +2304 +166 -165 -2305 imp:n=1 vol=320.4420 $ OFE radial fuelled region 4   16.5 - 17.5 cm
2545 355 8.014370000E-02   +2305 +166 -165 -2306 imp:n=1 vol=339.2920 $ OFE radial fuelled region 5   17.5 - 18.5 cm
2546 356 8.009850000E-02   +2306 +166 -165 -2307 imp:n=1 vol=358.1420 $ OFE radial fuelled region 6   18.5 - 19.5 cm
2547 357 8.005550000E-02   +2307 +166 -165 -2308 imp:n=1 vol=186.1390 $ OFE radial fuelled region 7   19.5 - 20.0 cm
2548 358 8.002710000E-02   +2308 +166 -165 -2309 imp:n=1 vol=190.8520 $ OFE radial fuelled region 8   20.0 - 20.5 cm
2549 359 8.000130000E-02   +2309 +166 -165 -2310 imp:n=1 vol=186.8600 $ OFE radial fuelled region 9   20.5 - 20.978 cm
c
c   Top - Axial Layer 16   (-16.0 - 19.0 cm)
2551 341 8.005830000E-02   +2301 +167 -166 -2302 imp:n=1 vol=106.9520 $ OFE radial fuelled region 1   15.12951 - 15.5 cm
2552 342 8.008950000E-02   +2302 +167 -166 -2303 imp:n=1 vol=148.4400 $ OFE radial fuelled region 2   15.5 - 16.0 cm
2553 343 8.012280000E-02   +2303 +167 -166 -2304 imp:n=1 vol=153.1530 $ OFE radial fuelled region 3   16.0 - 16.5 cm
2554 344 8.015300000E-02   +2304 +167 -166 -2305 imp:n=1 vol=320.4420 $ OFE radial fuelled region 4   16.5 - 17.5 cm
2555 345 8.014370000E-02   +2305 +167 -166 -2306 imp:n=1 vol=339.2920 $ OFE radial fuelled region 5   17.5 - 18.5 cm
2556 346 8.009850000E-02   +2306 +167 -166 -2307 imp:n=1 vol=358.1420 $ OFE radial fuelled region 6   18.5 - 19.5 cm
2557 347 8.005550000E-02   +2307 +167 -166 -2308 imp:n=1 vol=186.1390 $ OFE radial fuelled region 7   19.5 - 20.0 cm
2558 348 8.002710000E-02   +2308 +167 -166 -2309 imp:n=1 vol=190.8520 $ OFE radial fuelled region 8   20.0 - 20.5 cm
2559 349 8.000130000E-02   +2309 +167 -166 -2310 imp:n=1 vol=186.8600 $ OFE radial fuelled region 9   20.5 - 20.978 cm
c
c   Top - Axial Layer 17   (-19.0 - -22.0 cm)

2561 331 8.005830000E-02 +2301 +168 -167 -2302 imp:n=1 vol=106.9520 $ OFE radial fuelled region 1 15.12951 - 15.5 cm
2562 332 8.008950000E-02 +2302 +168 -167 -2303 imp:n=1 vol=148.4400 $ OFE radial fuelled region 2 15.5 - 16.0 cm
2563 333 8.012280000E-02 +2303 +168 -167 -2304 imp:n=1 vol=153.1530 $ OFE radial fuelled region 3 16.0 - 16.5 cm
2564 334 8.015300000E-02 +2304 +168 -167 -2305 imp:n=1 vol=320.4420 $ OFE radial fuelled region 4 16.5 - 17.5 cm
2565 335 8.014370000E-02 +2305 +168 -167 -2306 imp:n=1 vol=339.2920 $ OFE radial fuelled region 5 17.5 - 18.5 cm
2566 336 8.009850000E-02 +2306 +168 -167 -2307 imp:n=1 vol=358.1420 $ OFE radial fuelled region 6 18.5 - 19.5 cm
2567 337 8.005550000E-02 +2307 +168 -167 -2308 imp:n=1 vol=186.1390 $ OFE radial fuelled region 7 19.5 - 20.0 cm
2568 338 8.002710000E-02 +2308 +168 -167 -2309 imp:n=1 vol=190.8520 $ OFE radial fuelled region 8 20.0 - 20.5 cm
2569 339 8.000130000E-02 +2309 +168 -167 -2310 imp:n=1 vol=186.8600 $ OFE radial fuelled region 9 20.5 - 20.978 cm
c
c Top - Axial Layer 18 (-22.0 - -25.0 cm)
2571 321 8.005830000E-02 +2301 +169 -168 -2302 imp:n=1 vol=106.9520 $ OFE radial fuelled region 1 15.12951 - 15.5 cm
2572 322 8.008950000E-02 +2302 +169 -168 -2303 imp:n=1 vol=148.4400 $ OFE radial fuelled region 2 15.5 - 16.0 cm
2573 323 8.012280000E-02 +2303 +169 -168 -2304 imp:n=1 vol=153.1530 $ OFE radial fuelled region 3 16.0 - 16.5 cm
2574 324 8.015300000E-02 +2304 +169 -168 -2305 imp:n=1 vol=320.4420 $ OFE radial fuelled region 4 16.5 - 17.5 cm
2575 325 8.014370000E-02 +2305 +169 -168 -2306 imp:n=1 vol=339.2920 $ OFE radial fuelled region 5 17.5 - 18.5 cm
2576 326 8.009850000E-02 +2306 +169 -168 -2307 imp:n=1 vol=358.1420 $ OFE radial fuelled region 6 18.5 - 19.5 cm
2577 327 8.005550000E-02 +2307 +169 -168 -2308 imp:n=1 vol=186.1390 $ OFE radial fuelled region 7 19.5 - 20.0 cm
2578 328 8.002710000E-02 +2308 +169 -168 -2309 imp:n=1 vol=190.8520 $ OFE radial fuelled region 8 20.0 - 20.5 cm
2579 329 8.000130000E-02 +2309 +169 -168 -2310 imp:n=1 vol=186.8600 $ OFE radial fuelled region 9 20.5 - 20.978 cm
c
c Top - Axial Layer 19 (-25.0 - -25.4 cm)
2581 311 8.005830000E-02 +2301 +200 -169 -2302 imp:n=1 vol=14.2602 $ OFE radial fuelled region 1 15.12951 - 15.5 cm
2582 312 8.008950000E-02 +2302 +200 -169 -2303 imp:n=1 vol=19.7920 $ OFE radial fuelled region 2 15.5 - 16.0 cm
2583 313 8.012280000E-02 +2303 +200 -169 -2304 imp:n=1 vol=20.4204 $ OFE radial fuelled region 3 16.0 - 16.5 cm

2584 314 8.015300000E-02   +2304 +200 -169 -2305 imp:n=1 vol=42.7257 $ OFE radial fuelled region 4   16.5 - 17.5 cm
2585 315 8.014370000E-02   +2305 +200 -169 -2306 imp:n=1 vol=45.2389 $ OFE radial fuelled region 5   17.5 - 18.5 cm
2586 316 8.009850000E-02   +2306 +200 -169 -2307 imp:n=1 vol=47.7522 $ OFE radial fuelled region 6   18.5 - 19.5 cm
2587 317 8.005550000E-02   +2307 +200 -169 -2308 imp:n=1 vol=24.8186 $ OFE radial fuelled region 7   19.5 - 20.0 cm
2588 318 8.002710000E-02   +2308 +200 -169 -2309 imp:n=1 vol=25.4469 $ OFE radial fuelled region 8   20.0 - 20.5 cm
2589 319 8.000130000E-02   +2309 +200 -169 -2310 imp:n=1 vol=24.9147 $ OFE radial fuelled region 9   20.5 - 20.978 cm
c
c
2619 200 8.01309E-02   +2310 +200 -100 -2311 imp:n=1 vol=1023.2100 $outer unfuelled region
2500 20 6.02083E-02   +2311 +200 -100 -2400 imp:n=1 $OFE outer sidewall
c
2610 72 8.01308E-02   +2300 +100 -101 -2311 imp:n=1 $OFE unfuelled - upper region
2611 3   1.00053E-01   +2300 +101 -199 -2311 imp:n=1 $water above OFE upper region
2612 73 7.96002E-02   +2300 +201 -200 -2311 imp:n=1 $OFE unfuelled - lower region
2613 1   9.89921E-02   +2300 +299 -201 -2311 imp:n=1 $water below OFE upper region
c
2621 20 6.02083E-02   +2201 +202 -200 -2300 imp:n=1 $OFE inner sidewall lower extension
2623   1 9.89921E-02   +2201 +299 -202 -2300 imp:n=1 $water below OFE inner sidewall lower extension
c
2631 20 6.02083E-02   +2201 +100 -102 -2300 imp:n=1 $OFE inner sidewall upper extension
2633   3 1.00053E-01   +2201 -199 +102 -2300 imp:n=1 $water above OFE inner sidewall outer extension
c
2641 20 6.02083E-02   +2311 -200 +299 -2400 imp:n=1 $OFE outer sidewall-lower core support
c
2651 20 6.02083E-02   +2311 +100 -199 -2400 imp:n=1 $OFE outer sidewall-upper core support
c
c
c   ---
c   Region IV
c
c   CONTROL ELEMENTS REGION (CR)
c   ---

c
c
c The control element is region-4
c The control element region (CR) consists of 2 thin-walled (0.25 in)
c concentric cylindrical control elements.
c The inner cylinder is used for both shim and regulation. This rod moves
c upward to insert poison.
c The outer control cylinder is divided into 4 quadrants, and is used for
c shim and safety.
c Each control rod contains three longitudinal (axial) regions. A black region
c containing Europium (Eu-2O3), a gray region containing tantalum,and a
c white region containing aluminum, all clad with aluminum, making it an
c aluminum plate containing a black and gray cores.
c Control elements position is set using surface transformation cards
c (see CR surfaces).
c
c
c ----------------------------
c Control Element Cell Cards
c ----------------------------
c
3000 2 9.95227E-02 +2400 +200 -100 -3000 imp:n=1 $water between OFE outer sidewall and inner CR--active region
3001 3 1.00053E-01 +2400 -199 +100 -3000 imp:n=1 $water between OFE outer sidewall and inner CR--above active region
3002 1 9.89921E-02 +2400 +299 -200 -3000 imp:n=1 $water between OFE outer sidewall and inner CR--below active region
c
c Inner control element
c
3100 3 1.00053E-01 +3000 +300 -199 -3003 imp:n=1 $Inner element--Upper H2O (assume to top of model)
3101 1 9.89921E-02 +3000 +299 -304 -3003 imp:n=1 $Inner element--Lower H2O (assume to bottom of model)
c
3110 21 6.02083E-02 +3000 +304 -300 -3001 imp:n=1 $Inner element--Inner clad
3111 402 6.21902E-02 +3001 +301 -300 -3002 imp:n=1 $Inner element--Upper white region
c
3112 21 6.02083E-02 -700 +701 +3001 +303 -301 -3002 imp:n=1 $Inner element-Al gap region 1
3113 21 6.02083E-02 703 -702 +3001 +303 -301 -3002 imp:n=1 $Inner element-Al gap region 2
c

3114 400 6.02937E-02 +700 +702 +3001 +302 -301 -3002 imp:n=1 $Inner element--Gray region--Quad 1
3115 401 6.13221E-02 +700 +702 +3001 +303 -302 -3002 imp:n=1 $Inner element--Black region--Quad 1
3116 400 6.02937E-02 -703 +700 +3001 +302 -301 -3002 imp:n=1 $Inner element--Gray region--Quad 2
3117 401 6.13221E-02 -703 +700 +3001 +303 -302 -3002 imp:n=1 $Inner element--Black region--Quad 2
3118 400 6.02937E-02 -701 -703 +3001 +302 -301 -3002 imp:n=1 $Inner element--Gray region--Quad 3
3119 401 6.13221E-02 -701 -703 +3001 +303 -302 -3002 imp:n=1 $Inner element--Black region--Quad 3
3120 400 6.02937E-02 702 -701 +3001 +302 -301 -3002 imp:n=1 $Inner element--Gray region--Quad 4
3121 401 6.13221E-02 702 -701 +3001 +303 -302 -3002 imp:n=1 $Inner element--Black region--Quad 4
c
3122 403 6.21521E-02 +3001 +304 -303 -3002 imp:n=1 $Inner element--Lower white region
3123 21 6.02083E-02 +3002 +304 -300 -3003 imp:n=1 $Inner element--Outer clad
c
c Water between control elements
c
3200 2 9.95227E-02 +3003 +200 -100 -3004 imp:n=1 $water between inner CR and outer CR--active region
3201 3 1.00053E-01 +3003 -199 +100 -3004 imp:n=1 $water between inner CR and outer CR--above active region
3202 1 9.89921E-02 +3003 +299 -200 -3004 imp:n=1 $water between inner CR and outer CR--below active region
c
3300 3 1.00053E-01 +3004 +310 -199 -3099 imp:n=1 $Outer element--Upper H2O (assume to top of model)
3301 1 9.89921E-02 +3004 +299 -314 -3099 imp:n=1 $Outer element--Lower H2O (assume to bottom of model)
c
3302 70 8.01308E-02 -700 +701 +3004 +314 -310 -3099 imp:n=1 $Outer element--Total Water gap 1 (50% h2o,50% al)
3303 70 8.01308E-02 +703 -702 +3004 +314 -310 -3099 imp:n=1 $Outer element--Total Water gap 2 (50% h2o,50% al)
c
3304 21 6.02083E-02 +700 +702 +3004 +314 -310 -3005 imp:n=1 $Outer element--Inner clad-Quad 1
3305 21 6.02083E-02 -703 +700 +3004 +314 -310 -3005 imp:n=1 $Outer element--Inner clad-Quad 2

3306 21 6.02083E-02 -701 -703 +3004 +314 -310 -3005 imp:n=1 $Outer element--Inner clad-Quad 3
3307 21 6.02083E-02 +702 -701 +3004 +314 -310 -3005 imp:n=1 $Outer element--Inner clad-Quad 4
c
3308 412 6.20415E-02 +700 +702 +3005 +311 -310 -3006 imp:n=1 $Outer element--Upper white region-Quad 1
3309 412 6.20415E-02 -703 +700 +3005 +311 -310 -3006 imp:n=1 $Outer element--Upper white region-Quad 2
3310 412 6.20415E-02 -701 -703 +3005 +311 -310 -3006 imp:n=1 $Outer element--Upper white region-Quad 3
3311 412 6.20415E-02 +702 -701 +3005 +311 -310 -3006 imp:n=1 $Outer element--Upper white region-Quad 4
c
3312 410 6.13221E-02 +700 +702 +3005 +312 -311 -3006 imp:n=1 $Outer element--Black region-Quad 1
3313 411 6.02804E-02 +700 +702 +3005 +313 -312 -3006 imp:n=1 $Outer element--Gray region-Quad 1
3314 410 6.13221E-02 -703 +700 +3005 +312 -311 -3006 imp:n=1 $Outer element--Black region-Quad 2
3315 411 6.02804E-02 -703 +700 +3005 +313 -312 -3006 imp:n=1 $Outer element--Gray region-Quad 2
3316 410 6.13221E-02 -701 -703 +3005 +312 -311 -3006 imp:n=1 $Outer element--Black region-Quad 3
3317 411 6.02804E-02 -701 -703 +3005 +313 -312 -3006 imp:n=1 $Outer element--Gray region-Quad 3
3318 410 6.13221E-02 +702 -701 +3005 +312 -311 -3006 imp:n=1 $Outer element--Black region-Quad 4
3319 411 6.02804E-02 +702 -701 +3005 +313 -312 -3006 imp:n=1 $Outer element--Gray region-Quad 4
c
3320 413 6.21463E-02 +700 +702 +3005 +314 -313 -3006 imp:n=1 $Outer element--Lower white region-Quad 1
3321 413 6.21463E-02 -703 +700 +3005 +314 -313 -3006 imp:n=1 $Outer element--Lower white region-Quad 2
3322 413 6.21463E-02 -701 -703 +3005 +314 -313 -3006 imp:n=1 $Outer element--Lower white region-Quad 3
3323 413 6.21463E-02 +702 -701 +3005 +314 -313 -3006 imp:n=1 $Outer element--Lower white region-Quad 4
c
3324 21 6.02083E-02 +700 +702 +3006 +314 -310 -3099 imp:n=1 $Outer element--Outer clad-Quad 1
3325 21 6.02083E-02 -703 +700 +3006 +314 -310 -3099 imp:n=1 $Outer element--Outer clad-Quad 2
3326 21 6.02083E-02 -701 -703 +3006 +314 -310 -3099 imp:n=1 $Outer element--Outer clad-Quad 3

```
3327  21   6.02083E-02   +702  -701  +3006  +314  -310 -3099    imp:n=1   $Outer element--
Outer clad-Quad 4
c
c
c        -----------------------------------------
c                        Region V
c
c                 REMOVABLE REFLECTOR REGION
c        -----------------------------------------
c
c   The removable reflector is region-5
c   The Beryllium reflector region  is divided into 2 radial regions:
c      the innermost  is removable and can be replaced periodically.
c   The Beryllium reflectoris 24 cm in height.
c   The inner (removable) reflector dimensions are:
c      OD=23.756in ID=18.872in Height=24 cm
c   The reflector region has 20 vertical experiment facilities as follow:
c       Large removable beryllium (RB)  ...........8
c       Small removable beryllium (RB)  ...........4
c       Control-rod access plug facilities (CR) ...8
c
c   -----------------
c     RB Cell Cards
c   -----------------
c
c
4000  2   9.95227E-02    +3099  +201  -101 -4000  6350 6750 imp:n=1   $water just outside
outer CR--core region
4001  3   1.00053E-01    +3099  -199  +101 -4000   imp:n=1    $water just outside outer CR--
above core region
4002  1   9.89921E-02    +3099  +299  -201 -4000   imp:n=1    $water just outside outer CR--
below core region
c
4010  22  6.02083E-02    +4000  +201  -101 -4001 6350 6750  imp:n=1   $Al clad of
removable refl. reg. 1--core region
4011  3   1.00053E-01    +4000  -199  +101 -4001   imp:n=1    $water--above al clad
4012  1   9.89921E-02    +4000  +299  -201 -4001   imp:n=1    $water--below al clad
c
c     Removable Be Reflector Reg. 1
c     -----------------------------
4020  101  1.23607E-01    +4001  +201  -101 -4002
        6300 6350 6500 6550 6700 6750 6900 6950  imp:n=1   $removable refl. reg. 1--core
region
4021  6   1.00053E-01    +4001  -199  +101 -4002   imp:n=1   $water--above removable refl.
reg. 1
```

```
4022  4   9.89921E-02    +4001  +299  -201 -4002   imp:n=1   $water--below removable refl.
reg. 1
c
4030  5   9.95227E-02    +4002  +201  -101 -4003
        6300 6350 6500 6550 6700 6750 6900 6950  imp:n=1   $water region--core region
4031  6   1.00053E-01    +4002  -199  +101 -4003   imp:n=1   $water region--above core
region
4032  4   9.89921E-02    +4002  +299  -201 -4003   imp:n=1   $water region--below core
region
c
c     Removable Be Reflector Reg. 2
c     -----------------------------
4040  102 1.23607E-01    +4003  +201  -101 -4004
        6300 6350 6500 6550 6700 6750 6900 6950
        6400 6600 6800 7000                  imp:n=1   $removable refl. reg. 2--core region
4041  6   1.00053E-01    +4003  -199  +101 -4004   imp:n=1   $water--above removable refl.
reg. 2
4042  4   9.89921E-02    +4003  +299  -201 -4004   imp:n=1   $water--below removable refl.
reg. 2
c
4050  5   9.95227E-02    +4004  +201  -101 -4005
        6300 6350 6500 6550 6700 6750 6900 6950  imp:n=1   $water region--core region
4051  6   1.00053E-01    +4004  -199  +101 -4005   imp:n=1   $water region--above core
region
4052  4   9.89921E-02    +4004  +299  -201 -4005   imp:n=1   $water region--below core
region
c
c     Removable Be Reflector Reg. 3
c     -----------------------------
4060  103 1.23607E-01    +4005  +201  -101 -4006
        6300 6350 6500 6550 6700 6750 6900 6950  imp:n=1   $removable refl. reg. 3--core
region
4061  6   1.00053E-01    +4005  -199  +101 -4006   imp:n=1   $water--above removable refl.
reg. 3
4062  4   9.89921E-02    +4005  +299  -201 -4006   imp:n=1   $water--below removable refl.
reg. 3
c
4070  5   9.95227E-02    +4006  +201  -101 -4007 6350 6750   imp:n=1   $water region--core
region
4071  6   1.00053E-01    +4006  -199  +101 -4007   imp:n=1   $water region--above core
region
4072  4   9.89921E-02    +4006  +299  -201 -4007   imp:n=1   $water region--below core
region
c
c      Semi-permanent Be Reflector Region
c      ---------------------------------
```

```
c 4080  104 1.23607E-01    +4007  +201  -101 -4008          $semi-permanent refl. reg.--core
region
c         #(-7915)  #(-8015)   #(-8105) 6350 6750
c         7100 7200 7300 7400 7500 7600 7700 7800 imp:n=1   $ CR positions
4081  6   1.00053E-01    +4007  -199  +101 -4008   imp:n=1   $water--above semi-permanent
refl. reg.
4082  4   9.89921E-02    +4007  +299  -201 -4008   imp:n=1   $water--below semi-permanent
refl. reg.
c
c 4090  5   9.95227E-02    +4008  +201  -101 -4009          $water region--core region
c         #(-7915)  #(-8015)   #(-8105)          imp:n=1
4091  6   1.00053E-01    +4008  -199  +101 -4009   imp:n=1   $water region--above core
region
4092  4   9.89921E-02    +4008  +299  -201 -4009   imp:n=1   $water region--below core
region
c
4080  104 0.123607 4007 +201 -101 -4008                            $ Semi-permanent region
with CR positions
              8864 #(-8862 8856 -8855) #(-8861 -8856)              $ new HB 1 cutout
              8830 #(-8822 8842 -8844) #(-8821 8844)               $ new HB 4 cutout
              7915  8015                                 $ HB 2, 3 cutouts
              7100 7200 7300 7400 7500 7600 7700 7800      imp:n=1   $ control rod access
plugs
4090  1   -1.0     4008 +201 -101 -4009                              $ water gap
              8864 #(-8862 8856 -8855) #(-8861 -8856)              $ new HB 1 cutout
              8830 #(-8822 8842 -8844) #(-8821 8844)               $ new HB 4 cutout
              7915  8015                         imp:n=1   $ HB 2, 3 cutouts
c
c
c    ------------------------------
c    Removable Beryllium Facilities
c    ------------------------------
c
c      RB-1A   (Large Removable Be Facility)
6300  24   6.02083E-02    +6301  +201  -101 -6300  imp:n=1    $liner--core region
6301  33   1.23607E-01    -6301  +201  -101        imp:n=1    $inside liner-- core region
c
c      RB-1B   (Large Removable Be Facility)
6350  24   6.02083E-02    +6351  +201  -101 -6350  imp:n=1    $liner--core region
6351  530  6.02423E-02    -6351  +201  -101        imp:n=1    $inside liner--dummy Al target
c
c      RB-2   (Small Removable Be Facility)
6400  33   1.23607E-01    -6400  +201  -101        imp:n=1    $hole--core region
c
c      RB-3A   (Large Removable Be Facility)
6500  24   6.02083E-02    +6501  +201  -101 -6500  imp:n=1    $liner--core region
```

```
6501  530  6.02423E-02    -6501  +201  -101       imp:n=1    $inside liner--dummy Al target
c
c      RB-3B   (Large Removable Be Facility)
6550  24   6.02083E-02    +6551  +201  -101 -6550  imp:n=1    $liner--core region
6551  530  6.02423E-02    -6551  +201  -101       imp:n=1    $inside liner--dummy Al target
c
c      RB-4   (Small Removable Be Facility)
6600  33   1.23607E-01    -6600  +201  -101       imp:n=1    $hole--core region
c
c      RB-5A   (Large Removable Be Facility)
6700  24   6.02083E-02    +6701  +201  -101 -6700  imp:n=1    $liner--core region
6701  33   1.23607E-01    -6701  +201  -101       imp:n=1    $inside liner--core region
c
c      RB-5B   (Large Removable Be Facility)
6750  24   6.02083E-02    +6751  +201  -101 -6750  imp:n=1    $liner--core region
6751  33   1.23607E-01    -6751  +201  -101       imp:n=1    $inside liner--core region
c
c      RB-6   (Small Removable Be Facility)
6800  33   1.23607E-01    -6800  +201  -101       imp:n=1    $hole--core region
c
c      RB-7A   (RB-J17 loading in Large Removable Be Facility)
6900  38   -7.68237     +6901  +201  -101 -6900   imp:n=1    $liner--core region
6901  39   -4.66136     -6901  +201  -101        imp:n=1    $inside liner--core region
c
c      RB-7B   (Large Removable Be Facility)
6950  24   6.02083E-02    +6951  +201  -101 -6950  imp:n=1    $liner--core region
6951  530  6.02423E-02    -6951  +201  -101       imp:n=1    $inside liner--dummy Al target
c
c      RB-8   (Small Removable Be Facility)
7000  33   1.23607E-01    -7000  +201  -101       imp:n=1    $hole--core region
c
c   ----------------------------
c    RB Control Rod Access Plugs
c   ----------------------------
c
c      CR-1 or CR-1A  (Control Rod Access Plug 1)
7100  33   1.23607E-01    -7100  +201  -101       imp:n=1    $hole--core region
c
c      CR-2 or CR-1B
7200  33   1.23607E-01    -7200  +201  -101       imp:n=1    $hole--core region
c
c      CR-3 or CR-2A
7300  33   1.23607E-01    -7300  +201  -101       imp:n=1    $hole--core region
c                    #(-32003 -32002 +32004)
c
c      CR-4 or CR-2B
```

```
7400  33   1.23607E-01    -7400  +201  -101        imp:n=1    $hole--core region
c
c       CR-5 or CR-3A
7500  33   1.23607E-01    -7500  +201  -101        imp:n=1    $hole--core region
c
c       CR-6 or CR-3B
7600  33   1.23607E-01    -7600  +201  -101        imp:n=1    $hole--core region
c
c       CR-7 or CR-4A
7700  33   1.23607E-01    -7700  +201  -101        imp:n=1    $hole--core region
c
c       CR-8 or CR-4B
7800  33   1.23607E-01    -7800  +201  -101        imp:n=1    $hole--core region
c
c
c       -------------------------------------------
c                        Region VI
c
c               PERMANENT REFLECTOR REGION
c       -------------------------------------------
c
c  The permanent is region-6
c  The Beryllium reflector region  is devided into 2 radial regions:
c     the outermost  is permanent.
c  The outer (permanent) reflector dimensions are OD=43.0 Height=24cm
c  The reflector region has 4 engineering facilities and
c     22 vertical experiment facilities as follow:
c        Large VXF            6
c        Inner small VXF     11
c        outer small VXF      5
c  many parts of this region were modeled by Pepplow
c
C       ----------------------
C       Permanent Be Reflector
C       ----------------------
4104  6  1.00053E-01 4009 -4010 -199 +101  #(-4800 -199 +101)   imp:n=1   $ above outer
relfector
4105  4  9.89921E-02 4009 -4010 +299 -201                    imp:n=1   $ below outer relfector
9001  105 0.123156 4009 -4050 +201 -101                              $ the basic shape
                 8864 #(-8862 8856 -8855) #(-8861 -8856)              $ new HB 1 cutout
                 7915 #(-7906 -7950) #(-7905 -7949)                $ HB 2
                 #(-8006 8050 -8026) #(-8005 8026) 8015              $ HB 3
                 8830 #(-8822 8842 -8844) #(-8821 8844)       imp:n=1   $ new HB 4 cutout
9002  106 0.123156 4050 -4051 +201 -101                              $ the basic shape
                 4200 4400 4600 4800 5000 5200 5400 5600 5900 6100 6250 $ ring 2/3   vertical
experiments (small)
```

4300 4500 4900 5100 5300 $ ring 3/4/5 vertical experiments (small)
8864 #(-8862 8856 -8855) #(-8861 -8856) $ new HB 1 cutout
7915 #(-7906 -7950) #(-7905 -7949) $ HB 2
#(-8006 8050 -8026) #(-8005 8026) 8015 $ HB 3
8830 #(-8822 8842 -8844) #(-8821 8844) imp:n=1 $ new HB 4 cutout
9003 107 0.123156 4051 -4052 +201 -101 $ the basic shape
4200 4400 4600 4800 5000 5200 5400 5600 5900 6100 6250 $ ring 2/3 vertical experiments (small)
4300 4500 4900 5100 5300 $ ring 3/4/5 vertical experiments (small)
8864 #(-8862 8856 -8855) #(-8861 -8856) $ new HB 1 cutout
7915 #(-7906 -7950) #(-7905 -7949) $ HB 2
#(-8006 8050 -8026) #(-8005 8026) 8015 $ HB 3
8830 #(-8822 8842 -8844) #(-8821 8844) imp:n=1 $ new HB 4 cutout
9004 108 0.123156 4052 -4053 +201 -101 $ the basic shape
4300 4500 4900 5100 5300 $ ring 3/4/5 vertical experiments (small)
4700 5500 5700 5800 6000 6200 $ ring 4/5/6 vertical experiments (large)
8864 #(-8862 8856 -8855) #(-8861 -8856) $ new HB 1 cutout
7915 #(-7906 -7950) #(-7905 -7949) $ HB 2
#(-8006 8050 -8026) #(-8005 8026) 8015 $ HB 3
8830 #(-8822 8842 -8844) #(-8821 8844) imp:n=1 $ new HB 4 cutout
9005 109 0.123156 4053 -4054 +201 -101 $ the basic shape
4300 4500 4900 5100 5300 $ ring 3/4/5 vertical experiments (small)
4700 5500 5700 5800 6000 6200 $ ring 4/5/6 vertical experiments (large)
8864 #(-8862 8856 -8855) #(-8861 -8856) $ new HB 1 cutout
7915 #(-7906 -7950) #(-7905 -7949) $ HB 2
#(-8006 8050 -8026) #(-8005 8026) 8015 $ HB 3
8830 #(-8822 8842 -8844) #(-8821 8844) imp:n=1 $ new HB 4 cutout
9006 110 0.123156 4054 -4055 +201 -101 $ the basic shape
4700 5500 5700 5800 6000 6200 $ ring 4/5/6 vertical experiments (large)
8864 #(-8862 8856 -8855) #(-8861 -8856) $ new HB 1 cutout
7915 #(-7906 -7950) #(-7905 -7949) $ HB 2
#(-8006 8050 -8026) #(-8005 8026) 8015 $ HB 3
8830 #(-8822 8842 -8844) #(-8821 8844) $ new HB 4 cutout
8214 8234 imp:n=1 $ EF 1, 2
9007 111 0.123156 4055 -4010 +201 -101 $ the basic shape
8864 #(-8862 8856 -8855) #(-8861 -8856) $ new HB 1 cutout
7915 #(-7906 -7950) #(-7905 -7949) $ HB 2
#(-8006 8050 -8026) #(-8005 8026) 8015 $ HB 3
8830 #(-8822 8842 -8844) #(-8821 8844) $ new HB 4 cutout

```
             8214 8234                          imp:n=1   $ EF 1, 2
c
C      ------------------------------------
C      Water reflectors and pressure vessel
C      ------------------------------------
4110  7   1.00053E-01 4010 -4011  +299 -199               $ bit of water
       #(8840  -8821) 8861                          $ HB 1, 4
       #(-8214 201 -101)                          $ EF 1
       #(-8234 201 -101)                          $ EF 2
       #(-7905 -7950) #(-8005 8026)  imp:n=1            $ HB 2,3
4120  24  6.02083E-02  4011 -4012 +299 -199               $ Reflector Container
       #(8840  -8821) 8861                          $ HB 1, 4
       #(-8214 201 -101)                          $ EF 1
       #(-8234 201 -101)                          $ EF 2
       #(-7905 -7950) #(-8005 8026)  imp:n=1            $ HB 2,3
4130  7   1.00053E-01  4012 -4013 +299 -199               $ water
       #8215
       #8235
       #(-4018 +4012 -8840 -8875)                     $ HB 1
       #(-8003 8024)                              $ HB 2
       #(-7903 -7950) #(7932 -7931 -7934) #(-7936 -7932) $ HB 3
       #(-8900 +4012 +8840 -8800)                     $ HB 4
       #(-8214 201 -101)                          $ EF 1
       #(-8234 201 -101)   imp:n=1                    $ EF 2
4133  7   1.00053E-01  7938  4013 -7937 -7931 7936  imp:n=1 $
4140  40  8.62373E-02    4013 -4014 +299 -199             $ Pressure Vessel (inner liner)
       #(-4018 +4012 -8840 -8875)                     $ HB 1
       #(-8003 8024)                              $ HB 2
       #(-7903 -7950)  #(-7937 -7931)                  $ HB 3
       #(-8900 +4012 +8840 -8800)    imp:n=1            $ HB 4
4150  50  -8.16  4014 -4015 +299 -199                     $ Pressure Vessel
       #(-4018 +4012 -8840 -8875)                     $ HB 1
       #(-8003 8024)                              $ HB 2
       #(-7903 -7950)  #(-7937 -7931)                  $ HB 3
       #(-8900 +4012 +8840 -8800)    imp:n=1            $ HB 4
4153  50  -8.16        7938 4015 7937 -7939 -7931 imp:n=1  $
4160  40  8.62373E-02    4015 -4016 +299  -199            $ Pressure Vessel (outer liner)
       #(-4018 +4012 -8840 -8875)                     $ HB 1
       #(-8003 8024)                              $ HB 2
       #(-7939 -7931)                             $ HB 2 nozzle opening
       #(-7903 -7950)  #(-7937 -7931)                  $ HB 3
       #(-8900 +4012 +8840 -8800)    imp:n=1            $ HB 4
4170  8   1.01074E-01  +4016 -4017 +299 -199              $ pool
       #(+8900 -8910 -4018)                         $ HB 1
       #(-7936 -7950)  #(7938 -7939 -7931)              $ HB 2
       #(-8003 8024)                              $ HB 3
```

```
        #(+8900 -8910 -4018)                    $ HB 1
        #(-4018 +4012 -8840 -8875)                 $ HB 4
        #(-8900 +4012 +8840 -8800)  imp:n=1             $ HB 4
c
C     --------------------------------
C     VXF - located in outer reflector
C     --------------------------------
c     VXF-1   (Small Vertical Experiment Facility)  (water filled, ss liner)
4200  24  6.02083E-02    +4201  +201  -101 -4200    imp:n=1    $liner--core region
4201  9  9.95227E-02      -4201  +201  -101 +4202  imp:n=1    $water
4202  40  8.62373E-02    -4202  +201  -101 +4203    imp:n=1    $ss liner
4203  9  9.95227E-02      -4203  +201  -101       imp:n=1    $inside liner--core region
c     VXF-2   (Small Vertical Experiment Facility)
4300  24  6.02083E-02     +4301  +201  -101 -4300  imp:n=1    $liner--core region
4301  33  1.23607E-01    -4301  +201  -101         imp:n=1    $inside liner--core region
c     VXF-3   (Small Vertical Experiment Facility)  (water filled, ss liner)
4400  24  6.02083E-02     +4401  +201  -101 -4400  imp:n=1    $liner--core region
4401  9  9.95227E-02      -4401  +201  -101 +4402  imp:n=1    $water
4402  40  8.62373E-02     -4402  +201  -101 +4403  imp:n=1    $ss liner
4403  9  9.95227E-02      -4403  +201  -101       imp:n=1    $inside liner--core region
c     VXF-4   (Small Vertical Experiment Facility)
4500  24  6.02083E-02     +4501  +201  -101 -4500  imp:n=1    $liner--core region
4501  33  1.23607E-01     -4501  +201  -101       imp:n=1    $inside liner--core region
c     VXF-5   (Small Vertical Experiment Facility)  (water filled, ss liner)
4600  24  6.02083E-02     +4601  +201  -101 -4600  imp:n=1    $liner--core region
4601  9  9.95227E-02      -4601  +201  -101 +4602  imp:n=1    $water
4602  40  8.62373E-02     -4602  +201  -101 +4603  imp:n=1    $ss liner
4603  9  9.95227E-02      -4603  +201  -101       imp:n=1    $inside liner--core region
c     VXF-6   (Large Vertical Experiment Facility)
4700  24  6.02083E-02     +4701  +201  -101 -4700  imp:n=1    $liner--core region
4701  33  1.23607E-01     -4701  +201  -101       imp:n=1    $inside liner--core region
c     VXF-7  (Small Vertical Experiment Facility--Vertical Irradiation Facility)
4800  24  6.02083E-02     +4801  +201  -101 -4800  imp:n=1    $liner--core region
4801 60  2.00000-15      -4801  +201  -101 +4802  imp:n=1    $air space--core region
4802  24  6.02083E-02     -4802  +201  -101 +4803  imp:n=1    $flight tube--core region
4803 60  2.00000-15      -4803  +201  -101 4809   imp:n=1    $inside flight tube--core region
4809 60  2.00000-15      -4809                imp:n=1
4804  24  6.02083E-02     +4801  -199  +101 -4800  imp:n=1    $liner--above core region
4805 60  2.00000-15      -4801  -199  +101 +4802  imp:n=1    $air space--above core region
4806  24  6.02083E-02     -4802  -199  +101 +4803  imp:n=1    $flight tube--above core
region
4807 60  2.00000-15      -4803  -199  +101       imp:n=1    $inside flight tube--above core
region
c     VXF-8   (Small Vertical Experiment Facility)
4900  24  6.02083E-02     +4901  +201  -101 -4900  imp:n=1    $liner--core region
4901  33  1.23607E-01     -4901  +201  -101       imp:n=1    $inside liner--core region
```

```
c      VXF-9   (Small Vertical Experiment Facility)  (water filled, ss liner)
5000  24  6.02083E-02     +5001  +201  -101 -5000  imp:n=1    $liner--core region
5001  9  9.95227E-02      -5001  +201  -101 +5002  imp:n=1    $water
5002  40  8.62373E-02     -5002  +201  -101 +5003  imp:n=1    $ss liner
5003  9  9.95227E-02      -5003  +201  -101        imp:n=1    $inside liner--core region
c      VXF-10   (Small Vertical Experiment Facility)
5100  24  6.02083E-02     +5101  +201  -101 -5100  imp:n=1    $liner--core region
5101  33  1.23607E-01     -5101  +201  -101        imp:n=1    $inside liner--core region
c      VXF-11   (Small Vertical Experiment Facility)  (water filled, ss liner)
5200  24  6.02083E-02     +5201  +201  -101 -5200  imp:n=1    $liner--core region
5201  9  9.95227E-02      -5201  +201  -101 +5202  imp:n=1    $water
5202  40  8.62373E-02     -5202  +201  -101 +5203  imp:n=1    $ss liner
5203  9  9.95227E-02      -5203  +201  -101        imp:n=1    $inside liner--core region
c      VXF-12   (Small Vertical Experiment Facility)
5300  24  6.02083E-02     +5301  +201  -101 -5300  imp:n=1    $liner--core region
5301  33  1.23607E-01     -5301  +201  -101        imp:n=1    $inside liner--core region
c      VXF-13   (Small Vertical Experiment Facility)  (water filled, ss liner)
5400  24  6.02083E-02     +5401  +201  -101 -5400  imp:n=1    $liner--core region
5401  9  9.95227E-02      -5401  +201  -101 +5402  imp:n=1    $water
5402  40  8.62373E-02     -5402  +201  -101 +5403  imp:n=1    $ss liner
5403  9  9.95227E-02      -5403  +201  -101        imp:n=1    $inside liner--core region
c      VXF-14   (Large Vertical Experiment Facility)
5500  24  6.02083E-02     +5501  +201  -101 -5500  imp:n=1    $liner--core region
5501  33  1.23607E-01     -5501  +201  -101        imp:n=1    $inside liner--core region
c      VXF-15   (Small Vertical Experiment Facility)  (water filled, ss liner)
5600  24  6.02083E-02     +5601  +201  -101 -5600  imp:n=1    $liner--core region
5601  9  9.95227E-02      -5601  +201  -101 +5602  imp:n=1    $water
5602  40  8.62373E-02     -5602  +201  -101 +5603  imp:n=1    $ss liner
5603  9  9.95227E-02      -5603  +201  -101        imp:n=1    $inside liner--core region
c      VXF-16   (Large Vertical Experiment Facility)
5700  24  6.02083E-02     +5701  +201  -101 -5700  imp:n=1    $liner--core region
5701  33  1.23607E-01     -5701  +201  -101        imp:n=1    $inside liner--core region
c      VXF-17   (Large Vertical Experiment Facility)
5800  24  6.02083E-02     +5801  +201  -101 -5800  imp:n=1    $liner--core region
5801  33  1.23607E-01     -5801  +201  -101        imp:n=1    $inside liner--core region
c      VXF-18   (Small Vertical Experiment Facility)  (water filled, ss liner)
5900  24  6.02083E-02     +5901  +201  -101 -5900  imp:n=1    $liner--core region
5901  9  9.95227E-02      -5901  +201  -101 +5902  imp:n=1    $water
5902  40  8.62373E-02     -5902  +201  -101 +5903  imp:n=1    $ss liner
5903  9  9.95227E-02      -5903  +201  -101        imp:n=1    $inside liner--core region
c      VXF-19   (Large Vertical Experiment Facility)
6000  24  6.02083E-02     +6001  +201  -101 -6000  imp:n=1    $liner--core region
6001  33  1.23607E-01    -6001  +201  -101       imp:n=1    $inside liner--core region
c      VXF-20   (Small Vertical Experiment Facility)  (water filled, ss liner)
6100  24  6.02083E-02     +6101  +201  -101 -6100  imp:n=1    $liner--core region
6101  9  9.95227E-02      -6101  +201  -101 +6102  imp:n=1    $water
```

```
6102  40  8.62373E-02      -6102  +201  -101 +6103  imp:n=1    $ss liner
6103  9  9.95227E-02      -6103  +201  -101        imp:n=1    $inside liner--core region
c      VXF-21   (Large Vertical Experiment Facility)
6200  24  6.02083E-02    +6201  +201  -101 -6200    imp:n=1    $liner--core region
6201  33  1.23607E-01    -6201  +201  -101          imp:n=1    $inside liner--core region
c      VXF-22   (Small Vertical Experiment Facility)  (water filled, ss liner)
6250  24  6.02083E-02    +6251  +201  -101 -6250    imp:n=1    $liner--core region
6251  9  9.95227E-02     -6251  +201  -101 +6252    imp:n=1    $water
6252  40  8.62373E-02    -6252  +201  -101 +6253    imp:n=1    $ss liner
6253  9  9.95227E-02     -6253  +201  -101          imp:n=1    $inside liner--core region
c
C      ----------------------------------
C      Horizontal Beam Tube 1 - simplified
C      ----------------------------------
1200  60  2.00000E-15  -8880  8851                    imp:n=1
1201  60  2.00000E-15  -8870 -8851 -4018              imp:n=1
1211  24  6.02083E-02   8881 -8883  8853 -8850         imp:n=1
1212  24  6.02083E-02   8880 -8881  8851               imp:n=1
1213  24  6.02083E-02   8870 -8881  8853 -8851         imp:n=1
1214  24  6.02083E-02   8870 -8875  8860 -8853         imp:n=1
1280  24  6.02083E-02   8870 -8875 -8860 -4018         imp:n=1
1301   5  9.95227E-02   8883 -8865  8855               imp:n=1
1302   5  9.95227E-02   8881 -8883  8850               imp:n=1
1311   5  9.95227E-02   8883 -8863  8853 -8855         imp:n=1
1321   5  9.95227E-02   8875 -8863  8860 -8853         imp:n=1
1380   5  9.95227E-02   8875 -8863 -8860 -4012         imp:n=1
1401  24  6.02083E-02   8865 -8864 +8855               imp:n=1
1412  24  6.02083E-02   8863 -8862 -8855  8853         imp:n=1
1421  24  6.02083E-02   8863 -8862  8856 -8853         imp:n=1
1441  24  6.02083E-02   8863 -8861  8860 -8856         imp:n=1
1480  24  6.02083E-02   8863 -8861 -8860 -4012         imp:n=1
c
C      ----------------------------------
C      Horizontal Beam Tube 2 - simplified
C      ----------------------------------
7901  24  6.02083E-02   7900 -7903  7931 -7952  7991     imp:n=1
7902  24  6.02083E-02   7932 -7931  7933 -7934         imp:n=1
7903  24  6.02083E-02   7935 -7936 -7932 -4018         imp:n=1
7905  60  2.00000E-15   -7900  7925  7931 -7924        imp:n=1
7906  60  2.00000E-15    7932 -7931 -7933              imp:n=1
7907  60  2.00000E-15   -7935 -4018 -7932              imp:n=1
7910  60  2.0E-15 ((-7910 7951):(-7900 7924 -7951)) #(7920:7921) 7990 imp:n=1
c      Be insert inside tip of HB-2, Piece 1
7921  105  0.123156 (-7910:(-7900 7924 -7951)) 7920      -4050
           vol=1.218840                         imp:n=1  $ Vol of Cell 7921
7922  106  0.123156 (-7910:(-7900 7924 -7951)) 7920 4050 -4051
```

```
          vol=46.72155                              imp:n=1  $ Vol of Cell 7922
7923  107  0.123156 (-7910:(-7900 7924 -7951)) 7920 4051 -4052
          vol=101.8250                              imp:n=1  $ Vol of Cell 7923
7924  108  0.123156 (-7910:(-7900 7924 -7951)) 7920 4052 -4053
          vol=114.5370                              imp:n=1  $ Vol of Cell 7924
7925  109  0.123156 (-7910:(-7900 7924 -7951)) 7920 4053 -4054
          vol=101.9935                              imp:n=1  $ Vol of Cell 7925
7926  110  0.123156 (-7910:(-7900 7924 -7951)) 7920 4054 -4055
          vol=88.76903                              imp:n=1  $ Vol of Cell 7926
7927  111  0.123156 (-7910:(-7900 7924 -7951)) 7920 4055
          vol=87.04347                              imp:n=1  $ Vol of Cell 7927
c      Be insert inside tip of HB-2, Piece 2
7931  105  0.123156 (-7910:(-7900 7924 -7951)) 7921  -4050
          vol=1.218840                              imp:n=1  $ Vol of Cell 7931
7932  106  0.123156 (-7910:(-7900 7924 -7951)) 7921 4050 -4051
          vol=46.72155                              imp:n=1  $ Vol of Cell 7932
7933  107  0.123156 (-7910:(-7900 7924 -7951)) 7921 4051 -4052
          vol=101.8250                              imp:n=1  $ Vol of Cell 7933
7934  108  0.123156 (-7910:(-7900 7924 -7951)) 7921 4052 -4053
          vol=114.5370                              imp:n=1  $ Vol of Cell 7934
7935  109  0.123156 (-7910:(-7900 7924 -7951)) 7921 4053 -4054
          vol=101.9935                              imp:n=1  $ Vol of Cell 7935
7936  110  0.123156 (-7910:(-7900 7924 -7951)) 7921 4054 -4055
          vol=88.76903                              imp:n=1  $ Vol of Cell 7936
7937  111  0.123156 (-7910:(-7900 7924 -7951)) 7921 4055
          vol=87.04347                              imp:n=1  $ Vol of Cell 7937
c
79401  24  6.02083E-02   7910 -7911  7951             imp:n=1
79402  24  6.02083E-02   7900 -7911  7952 -7951        imp:n=1
79403  24  6.02083E-02   7911 -7913  7952 -7953        imp:n=1
79404  24  6.02083E-02   7900 -7903 -7952 -7991        imp:n=1
79501   5  9.95227E-02   7913 -7914  7950             imp:n=1
79502   5  9.95227E-02   7913 -7904  7952 -7950        imp:n=1
79503   5  9.95227E-02   7911 -7913  7953             imp:n=1
79504   5  9.95227E-02  -7904 -4012 -7952  7903        imp:n=1
79601  24  6.02083E-02   7904 -7905 -7949 -4012        imp:n=1
79602  24  6.02083E-02   7904 -7906  7949 -7950        imp:n=1
79603  24  6.02083E-02   7914 -7915  7950             imp:n=1
7997  60   2.00000E-15  -7990                         imp:n=1
c
C      -----------------------------------
C      Horizontal Beam Tube 3 - simplified
C      -----------------------------------
1600  60  2.00000E-15   -8010 -8022              imp:n=1
1603  60  2.00000E-15   -8000  8022 -4018         imp:n=1
1601  24  6.02083E-02    8011 -8013 -8024  8021    imp:n=1
```

```
1602  24  6.02083E-02    8010 -8011 -8022         imp:n=1
1612  24  6.02083E-02    8000 -8011  8022 -8024    imp:n=1
1660  24  6.02083E-02    8000 -8003  8024 -4018    imp:n=1
1701   5  9.95227E-02    8013 -8014 -8050 -8007    imp:n=1
1702   5  9.95227E-02    8011 -8013 -8021 -8007    imp:n=1
1711   5  9.95227E-02    8013 -8004  8050 -8024    imp:n=1
1712   5  9.95227E-02    8013 -8014 -8050  8007    imp:n=1
1721   5  9.95227E-02    8003 -8004  8024 -4012    imp:n=1
1801  24  6.02083E-02    8014 -8015 -8050         imp:n=1
1811  24  6.02083E-02    8004 -8006  8050 -8026    imp:n=1
1860  24  6.02083E-02    8004 -8005  8026 -4012    imp:n=1
c
C      ----------------------------------
C      Horizontal Beam Tube 4 - simplified
C      ----------------------------------
8800 60  2.00000E-15      ((-8835  +8602  -8625)
                   :(-8817  +8604  +8625  -8630)
                   :(-8817  +8630  -8845  +8622  +8624)
                   :(-8810  +8845  -8846  +8622  +8624)
                   :(-8803  +8846  -8901  +8622  +8624))
                   #(8604 -86254 86252 -86253)                   imp:n=1
9101  24  6.02083E-02  -8834  8835 -8625                        imp:n=1
9112  24  6.02083E-02  -8834  8817 -8842  8625                  imp:n=1
9113  24  6.02083E-02  -8816  8817  8842 -8843  8604            imp:n=1
88171 24  6.02083E-02  -8802  8803  8846 -8901                  imp:n=1
9121  24  6.02083E-02  -8814  8817  8843 -8845                  imp:n=1
9201  24  6.02083E-02   8834 -8842 -8833                        imp:n=1
9202  24  6.02083E-02   8833 -8832  8841 -8843                  imp:n=1
9203  24  6.02083E-02   8604  8816  8842 -8843 -8833            imp:n=1
88341 24  6.02083E-02  -8807  8810  8845 -8846 -8800            imp:n=1
88343 24  6.02083E-02  -8800  8802  8846 -8900                  imp:n=1
88431  5  9.95227E-02    -8823  8814  8843 -4012                imp:n=1
8844   5  9.95227E-02    -8800  4012  8840  8814 -8845          imp:n=1
8845   5  9.95227E-02    -8800  8807  8845                      imp:n=1
9301   5  9.95227E-02    -8831 8833 -8842 #(-8832 8841) -8604     imp:n=1
9311   5  9.95227E-02     8832 -8831 -8842 8604                 imp:n=1
9312   5  9.95227E-02     8832 8842 -8843 -8823  8604           imp:n=1
88531 24  6.02083E-02  -8821 8823  8555 -4012                   imp:n=1
9401  24  6.02083E-02  -8830 8831 -8842                         imp:n=1
9411  24  6.02083E-02  -8822 8823  8842 -8844                   imp:n=1
9441  24  6.02083E-02  -8821 8823  8844 -8554                   imp:n=1
9461  24  6.02083E-02  -8821 8823  8554 -8555 -4012  vol=182.4375  imp:n=1
c
C      -----------------------
C      Cold Source - simplified
C      -----------------------
```

```
86011  560  -0.0726  ((-8601 -86251):(86251 -8625 -8603))  #(-8606 -8608)
                                     vol=222.3432  imp:n=1
86021  24  6.02083E-02  ((-8602 8601 -86251):(86251 -8625 -8602 8603))
                                               imp:n=1
8603   60  2.00000E-15    -8605 -8607 -8626       vol=89.8163   imp:n=1
86041  24  6.02083E-02  -8606 -8608 -8626 #(-8605 -8607)
                                      vol=18.3353  imp:n=1
86051  560 -0.0726 -8603 8625 -8626 #(-8606 -8608) vol=134.55   imp:n=1
86061  24  6.02083E-02  -8604   8603   8625 -8626             imp:n=1
86062  24  6.02083E-02  86252 -86253 -86254  8604             imp:n=1
8607   60  2.0E-15  -8620 ((-8611 -8609 8626 #(-8627  (86271:86272)))
            : (-8604 (8616:8618)))          vol=412.290   imp:n=1
86083  20  -2.7 -8612 -8610 #(-8611 -8609)  -8618 -8616  8626 -8620
                                     vol=34.6019   imp:n=1
86085  24  6.02083E-02  -8627 -8611 (86271:86272) vol=6.277     imp:n=1
86091  560  -0.0726 (-8603 #(-8612 -8610) -8617 -8615 8626 -8620)
                                     vol=98.0855   imp:n=1
86101  24  6.02083E-02  -8604 8603 -8618 -8616 8626 -8620
                                     vol=30.3465   imp:n=1
86111  24  6.02083E-02  -8603 #(-8612 -8610) -8620
                ((8617 -8618):(8615 -8616)) vol=9.3975    imp:n=1
c     Inlet/Outlet nozzlE and stub region
8612  60  2.0E-15 -8604 ((8620 -8629 #(-86221 8611) #(-86241 8611))
        :(8629 -8630 8622 8624))              vol=274.2948  imp:n=1
86135  560  -0.0726 -8623   8620 -8630                    imp:n=1
86145  24  6.02083E-02     -86241  8623  8620  -8629 -8604  8611
                                     vol=2.53774   imp:n=1
86155  24  6.02083E-02     -8624   8623  8629  -8630          imp:n=1
86136  560 -0.0726  -8621   8620 -8630                    imp:n=1
86146  24  6.02083E-02     -86221  8621  8620  -8629 -8604  8611
                                     vol=2.53774   imp:n=1
86156  24  6.02083E-02     -8622   8621  8629  -8630
                                     vol=0.430958  imp:n=1
c     Inlet/Outlet coolant tubes
86137  560 -0.0726  -8623        8630  -8901          imp:n=1
86157  24  6.02083E-02     -8624   8623  8630  -8901     imp:n=1
86138  560 -0.0726  -8621        8630  -8901          imp:n=1
86158  24  6.02083E-02     -8622   8621  8630  -8901     imp:n=1
c
C      ------------------------------------------------------------------------
C      Portion of HB-4 beam tube and other in-tube components way out past vessel
C      ------------------------------------------------------------------------
8900  24  6.02083E-02   -8910  8802  8900  -8901        imp:n=1
8901  24  6.02083E-02   -8910  8911  8901  -8905        imp:n=1
8902  24  6.02083E-02   -8912  8803  8901  -8902        imp:n=1
8903  24  6.02083E-02   -8803  8901 -8903              imp:n=1
```

```
8904  24  6.02083E-02   -8803  8904 -8905              imp:n=1
8905  24  6.02083E-02   -8911  8803  8904  -8905        imp:n=1
8906  60  2.00000E-15   -8911  8901 -8904  #8902 #8903   imp:n=1
8907  60  2.00000E-15   -8910  8905 -4018              imp:n=1
c
C      ----------------------------------
C      Engineering Facilities (Slant tubes)
C      ----------------------------------
8210   7  1.00053E-01     -8210   +201  -101          imp:n=1
8211  24  6.02083E-02     8210  -8211 +201  -101       imp:n=1
8212   5  9.95227E-02    8211  -8212 +201  -101       imp:n=1
8213  24  6.02083E-02     8212  -8213 +201  -101       imp:n=1
8214   7  1.00053E-01    8213  -8214 +201  -101       imp:n=1
8215  24  6.02083E-02     8214  -8215 +4012 +201 -101  imp:n=1  $ Reflector Container
around EF
c
c
8230   7  1.00053E-01     -8230  8239  +201  -101     imp:n=1
8239   7  1.00053E-01     -8239        +201  -101     imp:n=1
8231  24  6.02083E-02     8230  -8231  +201  -101     imp:n=1
8232   7  1.00053E-01    8231  -8232  +201  -101     imp:n=1
8233  24  6.02083E-02     8232  -8233  +201  -101     imp:n=1
8234   7  1.00053E-01    8233  -8234  +201  -101     imp:n=1
8235  24  6.02083E-02     8234 -8235 +4012 +201 -101  imp:n=1
c
C      --------------------------------------
C      Concrete biological shield, with cutouts
C      --------------------------------------
9997  62  -3.09725 4017 -4018  -199 +299       $ basic shape
          #(-4018 +4012 -8840 -8875)           $ HB 1
          #(-7936 -7950)                       $ HB 2
          #(-8003  8024)                       $ HB 3
          #(+8900 -8910 -4018)        imp:n=1  $ HB 4
c
C      -------------
C      Outside World
C      -------------
9999   0    4018:+199:-299           imp:n=0
c
c     END-CELLS
c

c
c     ===================================    BEGIN-SURFACES
===================================
c
```

```
c     -------------------------
c      Flux Trap Target Region
c     -------------------------
c
199     pz    150.00    $ upper model boundary
299     pz   -150.00    $ lower model boundary
c
820     pz   +0.100     $ sample cell upper bound used to creat small cell for flux tallies
821     pz   -0.100     $ sample cell lower bound used to creat small cell for flux tallies
c
c        A-2 (shrouded Al dummy)
410 52    cz   0.24765     $ OD-target
411 52    cz   0.31623     $ OD-target clad
412 52    cz   0.47625     $ OD-holder
413 52    cz   0.755015    $ OD-coolant
414 52    cz   0.83058     $ OD-shroud
415 52    cz   0.83500     $ OD-coolant
c
416          pz  -25.40100    $ Shroud lower bound
417          pz  -39.6875     $ Target holder lower bound
418          pz   40.3225     $ Shroud upper bound
419          pz   49.2125     $ Target holder upper bound
c
c        A-3 (shrouded Al dummy)
420 53    cz   0.24765     $ OD-target
421 53    cz   0.31623     $ OD-target clad
422 53    cz   0.47625     $ OD-holder
423 53    cz   0.755015    $ OD-coolant
424 53    cz   0.83058     $ OD-shroud
425 53    cz   0.83500     $ OD-coolant
c
427          pz  -25.4        $ Target lower bound
428          pz   25.4        $ Target upper upper
c
c        B-1 (shrouded Al dummy)
430 54    cz   0.24765     $ OD-target
431 54    cz   0.31623     $ OD-target clad
432 54    cz   0.47625     $ OD-holder
433 54    cz   0.755015    $ OD-coolant
434 54    cz   0.83058     $ OD-shroud
435 54    cz   0.83500     $ OD-coolant
c
c        B-2 (shrouded Al dummy)
440 55    cz   0.24765     $ OD-target
441 55    cz   0.31623     $ OD-target clad
442 55    cz   0.47625     $ OD-holder
```

```
443 55    cz   0.755015    $ OD-coolant
444 55    cz   0.83058     $ OD-shroud
445 55    cz   0.83500     $ OD-coolant
c
c        B-3 (HT tube)
450 56    cz   0.32385     $ OD-target
451 56    cz   0.55499     $ OD-target clad
452 56    cz   0.63500     $ OD-air
453 56    cz   0.787400    $ OD-tube
454 56    cz   0.83500     $ OD-coolant
c
750         pz  29.28366       $ target bound
751         pz  28.80800       $ target bound
752         pz  23.251795      $ target bound
753         pz  22.77618       $ target bound
754         pz  22.300565      $ target bound
755         pz  16.744315      $ target bound
756         pz  16.26870       $ target bound
757         pz  15.793085      $ target bound
758         pz  10.236835      $ target bound
759         pz   9.76122       $ target bound
760         pz   9.285605      $ target bound
761         pz   3.729355      $ target bound
762         pz   3.25374       $ target bound
763         pz   2.778125      $ target bound
764         pz  -2.778125      $ target bound
765         pz  -3.25374       $ target bound
766         pz  -3.729355      $ target bound
767         pz  -9.285605      $ target bound
768         pz  -9.76122       $ target bound
769         pz  -10.236835     $ target bound
770         pz  -15.793085     $ target bound
771         pz  -16.26870      $ target bound
772         pz  -16.744315     $ target bound
773         pz  -22.300565     $ target bound
774         pz  -22.77618      $ target bound
775         pz  -23.251795     $ target bound
776         pz  -28.80800      $ target bound
777         pz  -29.28366      $ target bound
c
c         TAMU Target Rabbit heights
c
811 63     px    0.2505       $ Planes for SiC slot in Gd
812 63     px   -0.2505
813 63     py    0.07
814 63     py   -0.07
```

778 pz 14.795 $ Bottom of Al Housing
779 pz 15.114 $ Bottom of SS Holder
780 pz 15.474 $ Bottom of Bottom Stand
781 pz 15.974 $ Bottom of TEM Bottom Spacer
782 pz 16.236 $ Bottom of Insulator 1-Jan
783 pz 16.256 $ Bottom of TEM Sample 1
784 pz 16.276 $ Bottom of Insulator 2-Jan
785 pz 16.296 $ Bottom of Gd Center Spacer
786 pz 16.558 $ Bottom of Insulator 1-Feb
787 pz 16.578 $ Bottom of TEM Sample 2
788 pz 16.598 $ Bottom of Insulator 2-Feb
789 pz 16.618 $ Bottom of Gd Center Spacer
790 pz 16.88 $ Bottom of Insulator 1-Mar
791 pz 16.9 $ Bottom of TEM Sample 3
792 pz 16.92 $ Bottom of Insulator 2-Mar
793 pz 16.94 $ Bottom of Gd Center Spacer
794 pz 17.202 $ Bottom of Insulator 1-Apr
795 pz 17.222 $ Bottom of TEM Sample 4
796 pz 17.242 $ Bottom of Insulator 2-Apr
797 pz 17.262 $ Bottom of Gd Center Spacer
798 pz 17.524 $ Bottom of Insulator 1-May
799 pz 17.544 $ Bottom of TEM Sample 5
800 pz 17.564 $ Bottom of Insulator 2-May
801 pz 17.584 $ Bottom of Gd Center Spacer
802 pz 17.846 $ Bottom of Insulator 1-Jun
803 pz 17.866 $ Bottom of TEM Sample 6
804 pz 17.886 $ Bottom of Insulator 2-Jun
805 pz 17.906 $ Bottom of TEM Top Spacer
806 pz 18.168 $ Bottom of Spring Void
807 pz 20.279 $ Bottom of TEM Holder End Cap
808 pz 20.596 $ Bottom of Al Housing Void
809 pz 20.946 $ Bottom of Al End Cap
810 pz 21.261 $ Top of Al End Cap
815 pz 18.021 $ Middle of TEM Top Spacer/Top of 6th Gd Gap
816 pz 16.389 $ Top of TEM Bottom Spacer/Bottom of 1st Gd Gap
817 pz 16.411 $ Top of 1st Gd Gap
818 pz 16.711 $ Bottom of 2nd Gd Gap
819 pz 16.733 $ Top of 2nd Gd Gap
822 pz 17.033 $ Bottom of 3rd Gd Gap
823 pz 17.055 $ Top of 3rd Gd Gap
824 pz 17.355 $ Bottom of 4th Gd Gap
825 pz 17.377 $ Top of 4th Gd Gap
826 pz 17.677 $ Bottom of 5th Gd Gap
827 pz 17.699 $ Top of 5th Gd Gap
828 pz 17.999 $ Bottom of 6th Gd Gap
829 pz 20.446 $ Bottom of TEM Holder End Cap depression

```
c
c
c       B-4 (shrouded Al dummy)
460 57   cz  0.24765    $ OD-target
461 57   cz  0.31623    $ OD-target clad
462 57   cz  0.47625    $ OD-holder
463 57   cz  0.755015   $ OD-coolant
464 57   cz  0.83058    $ OD-shroud
465 57   cz  0.83500    $ OD-coolant
c
c       B-5 (shrouded Al dummy)
470 58   cz  0.24765    $ OD-target
471 58   cz  0.31623    $ OD-target clad
472 58   cz  0.47625    $ OD-holder
473 58   cz  0.755015   $ OD-coolant
474 58   cz  0.83058    $ OD-shroud
475 58   cz  0.83500    $ OD-coolant
c
c       C-1 (shrouded Al dummy)
480 59   cz  0.24765    $ OD-target
481 59   cz  0.31623    $ OD-target clad
482 59   cz  0.47625    $ OD-holder
483 59   cz  0.755015   $ OD-coolant
484 59   cz  0.83058    $ OD-shroud
485 59   cz  0.83500    $ OD-coolant
c
c       C-2 (solid Al dummy)
492 60   cz  0.47625    $ OD-holder
494 60   cz  0.83058    $ OD-shroud
495 60   cz  0.83500    $ OD-coolant
c
c       C-3 (shrouded Al dummy)
510 61   cz  0.24765    $ OD-target
511 61   cz  0.31623    $ OD-target clad
512 61   cz  0.47625    $ OD-holder
513 61   cz  0.755015   $ OD-coolant
514 61   cz  0.83058    $ OD-shroud
515 61   cz  0.83500    $ OD-coolant
c
c       C-4 (Shrouded Al dummy)
520 62   cz  0.24765    $ OD-target
521 62   cz  0.31623    $ OD-target clad
522 62   cz  0.47625    $ OD-holder
523 62   cz  0.755015   $ OD-coolant
524 62   cz  0.83058    $ OD-shroud
525 62   cz  0.83500    $ OD-coolant
```

```
c
c       C-5 (solid Al dummy)
532 63   cz   0.47625    $ OD-holder
534 63   cz   0.83058    $ OD-shroud
535 63   cz   0.83500    $ OD-coolant
530 63   cz   0.476      $ Outer Al Housing Radius (Guess)
531 63   cz   0.471      $ Outer SS Holder Radius
533 63   cz   0.153      $ Radius of TEM Samples
536 63   cz   0.3305     $ GD Spacer Outer Radius
537 63   cz   0.28       $ Bottom Stand Inner Radius
538 63   cz   0.024      $ Center Hole in Gd Spacers
539 63   cz   0.251      $ TEM Holder End Cap Depression
c
c       C-6 (JP-26 SST-304  targets)
542 64   cz   0.635      $ OD- sst target and its holder .5 in od
543 64   cz    0.75565   $ Shroud ID (OD-coolant)
544 64   cz   0.83058    $ OD-shroud
545 64   cz   0.83500    $ OD-coolant
c
c       D-2 (shrouded Al dummy)
550 65   cz   0.24765    $ OD-target
551 65   cz   0.31623    $ OD-target clad
552 65   cz   0.47625    $ OD-holder
553 65   cz   0.755015   $ OD-coolant
554 65   cz   0.83058    $ OD-shroud
555 65   cz   0.83500    $ OD-coolant
c
c       D-3 (solid Al dummy)
562 66   cz   0.47625    $ OD-holder
564 66   cz   0.83058    $ OD-shroud
565 66   cz   0.83500    $ OD-coolant
c
c       D-4 (solid Al dummy)
572 67   cz   0.47625    $ OD-holder
574 67   cz   0.83058    $ OD-shroud
575 67   cz   0.83500    $ OD-coolant
c
c       D-5 (shrouded Al dummy)
580 68   cz   0.24765    $ OD-target
581 68   cz   0.31623    $ OD-target clad
582 68   cz   0.47625    $ OD-holder
583 68   cz   0.755015   $ OD-coolant
584 68   cz   0.83058    $ OD-shroud
585 68   cz   0.83500    $ OD-coolant
c
c       D-6 (shrouded Al dummy)
```

```
590 69    cz   0.24765    $ OD-target
591 69    cz   0.31623    $ OD-target clad
592 69    cz   0.47625    $ OD-holder
593 69    cz   0.755015   $ OD-coolant
594 69    cz   0.83058    $ OD-shroud
595 69    cz   0.83500    $ OD-coolant
c
c        E-2 (JP-27 SST-304  targets)
612 70    cz   0.635      $ OD- sst target and its holder .5 in od
613 70    cz   0.75565    $ Shroud ID (OD-coolant)
614 70    cz   0.83058    $ OD-shroud
615 70    cz   0.83500    $ OD-coolant
c
c        E-3 (shrouded Al dummy)
620 71    cz   0.24765    $ OD-target
621 71    cz   0.31623    $ OD-target clad
622 71    cz   0.47625    $ OD-holder
623 71    cz   0.755015   $ OD-coolant
624 71    cz   0.83058    $ OD-shroud
625 71    cz   0.83500    $ OD-coolant
c
c        E-4 (shrouded Al dummy)
630 72    cz   0.24765    $ OD-target
631 72    cz   0.31623    $ OD-target clad
632 72    cz   0.47625    $ OD-holder
633 72    cz   0.755015   $ OD-coolant
634 72    cz   0.83058    $ OD-shroud
635 72    cz   0.83500    $ OD-coolant
c
c        E-5 (solid Al dummy)
642 73    cz   0.47625    $ OD-holder
644 73    cz   0.83058    $ OD-shroud
645 73    cz   0.83500    $ OD-coolant
c
c        E-6 (solid Al dummy)
652 74    cz   0.47625    $ OD-holder
654 74    cz   0.83058    $ OD-shroud
655 74    cz   0.83500    $ OD-coolant
c
c        E-7 (shrouded Al dummy)
660 75    cz   0.24765    $ OD-target
661 75    cz   0.31623    $ OD-target clad
662 75    cz   0.47625    $ OD-holder
663 75    cz   0.755015   $ OD-coolant
664 75    cz   0.83058    $ OD-shroud
665 75    cz   0.83500    $ OD-coolant
```

```
c
c        F-3 (shrouded Al dummy)
670 76    cz   0.24765    $ OD-target
671 76    cz   0.31623    $ OD-target clad
672 76    cz   0.47625    $ OD-holder
673 76    cz   0.755015   $ OD-coolant
674 76    cz   0.83058    $ OD-shroud
675 76    cz   0.83500    $ OD-coolant
c
c        F-4 (shrouded Al dummy)
680 77    cz   0.24765    $ OD-target
681 77    cz   0.31623    $ OD-target clad
682 77    cz   0.47625    $ OD-holder
683 77    cz   0.755015   $ OD-coolant
684 77    cz   0.83058    $ OD-shroud
685 77    cz   0.83500    $ OD-coolant
c
c        F-5 (solid Al dummy)
692 78    cz   0.47625    $ OD-holder
694 78    cz   0.83058    $ OD-shroud
695 78    cz   0.83500    $ OD-coolant
c
c        F-6 (shrouded Al dummy)
710 79    cz   0.24765    $ OD-target
711 79    cz   0.31623    $ OD-target clad
712 79    cz   0.47625    $ OD-holder
713 79    cz   0.755015   $ OD-coolant
714 79    cz   0.83058    $ OD-shroud
715 79    cz   0.83500    $ OD-coolant
c
c        F-7 (shrouded Al dummy)
720 80    cz   0.24765    $ OD-target
721 80    cz   0.31623    $ OD-target clad
722 80    cz   0.47625    $ OD-holder
723 80    cz   0.71374    $ OD-coolant
724 80    cz   0.83058    $ OD-shroud
725 80    cz   0.83500    $ OD-coolant
c
c        G-5 (shrouded Al dummy)
730 81    cz   0.24765    $ OD-target
731 81    cz   0.31623    $ OD-target clad
732 81    cz   0.47625    $ OD-holder
733 81    cz   0.755015   $ OD-coolant
734 81    cz   0.83058    $ OD-shroud
735 81    cz   0.83500    $ OD-coolant
c
```

```
c        G-6 (shrouded Al dummy)
740 82   cz   0.24765    $ OD-target
741 82   cz   0.31623    $ OD-target clad
742 82   cz   0.47625    $ OD-holder
743 82   cz   0.755015   $ OD-coolant
744 82   cz   0.83058    $ OD-shroud
745 82   cz   0.83500    $ OD-coolant
c
c       750 and 760 and 770 used for targets in HT tube
c
c          PTP- 5  (G-7)
900 45   cz   0.548640   $ Capsule outer radius
901 45   cz   0.47625    $ OD-clad
902 45   cz   0.7874     $ OD-water coolant
903 45   cz   0.8890     $ OD-shroud
904 45   cz   0.92964    $ OD-coolant
905 45   cz   1.00076    $ OD-container
c
907          pz  -31.74873   $ PTP shroud lower bound
908          pz  -34.60623   $ PTP lower bound target
909          pz   27.861895  $ PTP upper bound target
c
c          PTP-4 (D-7)
910 46   cz  0.548640    $ Capsule outer radius
911 46   cz   0.47625    $ OD-clad
912 46   cz   0.7874     $ OD-water coolant
913 46   cz   0.8890     $ OD-shroud
914 46   cz   0.92964    $ OD-coolant
915 46   cz   1.00076    $ OD-container
c
c          PTP-1 (A-4)
920 47   cz   0.548640   $ OD- Capsule
921 47   cz   0.47625    $ OD-clad
922 47   cz   0.7874     $ OD-water coolant
923 47   cz   0.8890     $ OD-shroud
924 47   cz   0.92964    $ OD-coolant
925 47   cz   1.00076    $ OD-container
c
c          PTP-3 (A-1)
930 48   cz  0.548640    $ Capsule outer radius
931 48   cz   0.47625    $ OD-clad
932 48   cz   0.7874     $ OD-water coolant
933 48   cz   0.8890     $ OD-shroud
934 48   cz   0.92964    $ OD-coolant
935 48   cz   1.00076    $ OD-container
c
```

```
c         PTP-2 (D-1)
940 49   cz  0.548640    $ Capsule outer radius
941 49   cz   0.47625    $ OD-clad
942 49   cz   0.7874     $ OD-water coolant
943 49   cz   0.8890     $ OD-shroud
944 49   cz   0.92964    $ OD-coolant
945 49   cz   1.00076    $ OD-container
c
c         PTP-6 (G-4)
950 50   cz  0.548640    $ Capsule outer radius
951 50   cz   0.47625    $ OD-clad
952 50   cz   0.7874     $ OD-water coolant
953 50   cz   0.8890     $ OD-shroud
954 50   cz   0.92964    $ OD-coolant
955 50   cz   1.00076    $ OD-container
c
c      PTP Target Capsule planes
c
970    pz -25.0      $bottom of first capsule
971    pz -18.469660  $ Top of first Capsule capsule height 6.530340 cm
972    pz -11.939320  $ Top of second capsule
973    pz -5.408980
974    pz 1.121360
975    pz 7.651700
976    pz 14.182040
977    pz 20.712380
978    cz 0.548640    $ Capsule outer radius
c
c
c         Target Basket
960    cz   5.71500     $ ID-basket
961    cz   5.87375     $ OD-basket
c
c
c    ------------------------------
c     Inner Fuel element  Surfaces
c    ------------------------------
c
c     Reference 1 is Silverton 1971 report
c     Reference 2 is ornl- DWG 61472AR3
c
c
100    pz    25.4        $ IFE & OFE upper bound of active fuel area - top of axial layer 1
150    pz    25.0        $ IFE & OFE upper bound of active fuel area - top of axial layer 2
151    pz    22.0        $ IFE & OFE upper bound of active fuel area - top of axial layer 3
153    pz    19.0        $ IFE & OFE upper bound of active fuel area - top of axial layer 4
```

```
154     pz     16.0          $ IFE & OFE upper bound of active fuel area - top of axial layer 5
155     pz     13.0          $ IFE & OFE upper bound of active fuel area - top of axial layer 6
156     pz     10.0          $ IFE & OFE upper bound of active fuel area - top of axial layer 7
157     pz     7.0           $ IFE & OFE upper bound of active fuel area - top of axial layer 8
158     pz     4.0           $ IFE & OFE upper bound of active fuel area - top of axial layer 9
159     pz     1.0           $ IFE & OFE upper bound of active fuel area - top of axial layer 10
161     pz    -1.0           $ IFE & OFE upper bound of active fuel area - top of axial layer 11
162     pz    -4.0           $ IFE & OFE upper bound of active fuel area - top of axial layer 12
163     pz    -7.0           $ IFE & OFE upper bound of active fuel area - top of axial layer 13
164     pz    -10.0          $ IFE & OFE upper bound of active fuel area - top of axial layer 14
165     pz    -13.0          $ IFE & OFE upper bound of active fuel area - top of axial layer 15
166     pz    -16.0          $ IFE & OFE upper bound of active fuel area - top of axial layer 16
167     pz    -19.0          $ IFE & OFE upper bound of active fuel area - top of axial layer 17
168     pz    -22.0          $ IFE & OFE upper bound of active fuel area - top of axial layer 18
169     pz    -25.0          $ IFE & OFE upper bound of active fuel area - top of axial layer 19
c
200     pz    -25.4          $ lower bound of active fuel area - bottom of axial layer 7
101     pz     30.48         $ upper bound of uncontrolled fuel area
201     pz    -30.48         $ lower bound of uncontrolled fuel area
202     pz    -37.1475       $ lower extension IFE outer, OFE inner sidewall
102     pz     41.91         $ upper extension IFE outer, OFE inner sidewall
c
1999    cz     6.43509       $ inner radius--IFE inner sidewall [Ref2]
2000    cz     6.88302       $ outer radius--IFE inner sidewall
2001    cz     7.14          $ outer radius--IFE inner gap [Ref1]
2002    cz     7.5           $ outer radius--IFE Region 1
2003    cz     8.0           $ outer radius--IFE Region 2
2004    cz     8.5           $ outer radius--IFE Region 3
2005    cz     9.5           $ outer radius--IFE Region 4
2006    cz     10.5          $ outer radius--IFE Region 5
2007    cz     11.5          $ outer radius--IFE Region 6
2008    cz     12.0          $ outer radius--IFE Region 7
2009    cz     12.60         $ outer radius--IFE Region 8 [Ref1]
2010    cz     12.82700      $ outer radius--IFE outer gap
2200    cz     13.44930      $ outer radius--IFE outer sidewall [Ref2]
c
c   -----------------------------
c    Outer Fuel Element Surfaces
c   -----------------------------
c
2201    cz     14.28750   $ outer radius--water gap between IFE/OFE [Ref2]
2300    cz     14.91869   $ outer radius--OFE inner sideplate
2301    cz     15.12951   $ outer radius--OFE inner gap
2302    cz     15.5       $ outer radius--OFE radial fuelled region 1
2303    cz     16.0       $ outer radius--OFE radial fuelled region 2
2304    cz     16.5       $ outer radius--OFE radial fuelled region 3
```

```
2305   cz    17.5      $ outer radius--OFE radial fuelled region 4
2306   cz    18.5      $ outer radius--OFE radial fuelled region 5
2307   cz    19.5      $ outer radius--OFE radial fuelled region 6
2308   cz    20.0      $ outer radius--OFE radial fuelled region 7
2309   cz    20.5      $ outer radius--OFE radial fuelled region 8
2310   cz    20.978    $ outer radius--OFE radial fuelled region 9 [ref1]
2311   cz    21.13026  $ outer radius--OFE outer gap
2400   cz    21.7475   $ outer radius--OFE outer sideplate [Ref2]
c
c
c   -------------------------
c    Control Element Surfaces
c   -------------------------
c
c                        Control Plates Dimensions
c      ________________________________________
________________________________________
c          Inner Control Plate                    Outer Control Plate
c      ________________________________________
________________________________________
c
c      White Region  Aluminum 68.73875 cm       White Region  Aluminum  21.9075 cm
c
c      Black Region  Tantalum 12.7 cm           Gray Region   Europium  55.88 cm
c
c      Gray Region   Europium 55.88 cm          Black Region  Tantalum  12.7 cm
c
c      White Region  Aluminum 36.35375 cm       White Region  Aluminum  77.62875 cm
c    ------------------------------------------------------------------------------
c
c    Upper and lower bound of VXF's, RB's, and CR's
c
401        pz    -30.48     $ upper bound of facilities
501        pz    +30.48     $ lower bound of facilities
c
700 51   py    +1.27      $ plane to divide control elements
701 51   py    -1.27      $ plane to divide control elements
702 51   px    +1.27      $ plane to divide control elements
703 51   px    -1.27      $ plane to divide control elements
c
c                  -----------------------
c                   Control Rod Positions
c                  -----------------------
c
c     inner moves down outer moves up
c
```

```
c     ____________________
______________________________________________________________
c     Transformation No.
c     Inner       Outer                  Cycle Time
c     ____________________
______________________________________________________________
c     83    and    84           SHUTDOWN - 0.0 inch - shutdown (black regions at upper/lower
edge of unfuelled core region)
c     85    and    86           FULLY INSERTED - 2.0 inch - startup (black regions at
upper/lower edge of active region)
c     87    and    88           STARTUP - 18.0 inch - 0.0 days
c     89    and    90           Xe - 19.25 inch - 1.0 days
c     91    and    92           Boron Burn - 20.25 inch - 2.0 days
c     93    and    94           21.00 inch - 10.0 days
c     95    and    96           23.50 inch - 18.0 days
c     97    and    98           25.00 inch - 20.0 days
c     99    and    100          AVERAGE POSITION - 22.0 inch - 14.0 days
c    101    and    102          FULLY WITHDRAWN - 27.0 inch - EOC (white regions at
upper/lower edge of active region)
c
c
c    BOC Shutdown positions ( Trent P. 8/22/04)
c
c    Inner Element
300 100    pz    111.91875      $ Upper bound of upper white  region -- inner element
301 100    pz     43.18         $ Upper bound of gray region -- inner element ( Actual position is
-2.54 cm )
302 100    pz     30.48         $ Upper bound of black region -- inner element ( Actual position
is -15.24 cm)
303 100    pz    -25.40         $ Upper bound of lower white region -- inner element
304 100    pz    -61.75375      $ Upper bound of water below lower white region -- inner
element
c
c    Outer Element
310 200    pz     47.3075       $ Upper bound of upper white  region -- outer element
311 200    pz     25.40         $ Upper bound of black region -- outer element
312 200    pz    -30.48         $ Upper bound of gray region -- outer element
313 200    pz    -43.18         $ Upper bound of lower white region -- outer element
314 200    pz   -120.80875      $ Upper bound of water below lower white region -- outer
element
c
c
3000    cz     22.02434         $ outer radius--water gap between core/ICE
3001    cz     22.103715        $ outer radius--Inner control element(ICE) inner clad
3002    cz     22.579965        $ outer radius--ICE control region
3003    cz     22.659340        $ outer radius--ICE outer clad
```

```
3004   cz   22.987         $ outer radius--water gap between ICE/OCE
3005   cz   23.066375        $ outer radius--OCE inner clad
3006   cz   23.542625        $ outer radius--OCE control region
3099   cz   23.622         $ outer radius--OCE outer clad
4000   cz   23.8125         $ outer radius--water gap between OCE/remov. Be refl.
c
c    ------------------------------
c     Removable  Reflector Surfaces
c    ------------------------------
c
600    px     0.00     $ plane to cut permanent Be Reflector
601    py     0.00     $ plane to cut permanent Be Reflector
c
4001   cz   24.4475   $ outer radius--Al clad
4002   cz   25.0825   $ outer radius--remov. Be refl. reg. 1
4003   cz   25.15108   $ outer radius--water gap
4004   cz   27.46375   $ outer radius--remov. Be refl. reg. 2
4005   cz   27.53233   $ outer radius--water gap
4006   cz   30.25267   $ outer radius--remov. Be refl. reg. 3
4007   cz   30.32125   $ outer radius--water gap
4008   cz   33.02     $ outer radius--semi-permanent Be refl. reg.
4009   cz   33.3375   $ outer radius--water gap
c
c   ------------------------------------------
c    Removable Reflector Irradiation Facilities
c   ------------------------------------------
c
c         RB-1A
6300 23   cz   2.59080   $ liner OD
6301 23   cz   2.32918   $ liner ID
c
c         RB-1B
6350 24   cz   2.59080   $ liner OD
6351 24   cz   2.32918   $ liner ID
c
c         RB-2
6400 25   cz   0.63500   $ OD
c
c         RB-3A
6500 26   cz   2.59080   $ liner OD
6501 26   cz   2.32918   $ liner ID
c
c         RB-3B
6550 27   cz   2.59080   $ liner OD
6551 27   cz   2.32918   $ liner ID
c
```

```
c          RB-4
6600 28   cz   0.63500    $ OD
c
c          RB-5A
6700 29   cz   2.59080    $ liner OD
6701 29   cz   2.32918    $ liner ID
c
c          RB-5B
6750 30   cz   2.59080    $ liner OD
6751 30   cz   2.32918    $ liner ID
c
c          RB-6
6800 31   cz   0.63500    $ OD
c
c          RB-7A (RB - 7J)
6900 32   cz   2.54       $ liner OD  from ref 5.1 calculations
6901 32   cz   2.049       $ liner ID  from ref 5.1 calculations
c
c          RB-7B
6950 33   cz   2.54       $ liner OD
6951 33   cz   2.049       $ liner ID
c
c          RB-8
7000 34   cz   0.63500    $ OD
c
c
c          CR-1
7100 35   cz   0.63500    $ OD
c
c          CR-2
7200 36   cz   0.63500    $ OD
c
c          CR-3
7300 37   cz   0.63500    $ OD
c
c          CR-4
7400 38   cz   0.63500    $ OD
c
c          CR-5
7500 39   cz   0.63500    $ OD
c
c          CR-6
7600 40   cz   0.63500    $ OD
c
c          CR-7
7700 41   cz   0.63500    $ OD
```

```
c
c          CR-8
7800 42    cz   0.63500    $ OD
c
c
c     -------------------------------
c      Permanent  Reflector  Surfaces
c     -------------------------------
c
4010    cz     54.61      $ outer radius--permanent Be refl. reg.
4011    cz     55.245     $ outer radius--water gap
4012    cz     56.8325    $ outer radius--Al tank
4013    cz     119.38     $ outer radius--water
4014    cz     119.6975   $ outer radius--inner pressure vessel clad
4015    cz     127.0      $ outer radius--pressure vessel
4016    cz     127.254    $ outer radius--outer pressure vessel clad
4017    cz     274.32     $ outer radius--H2O pool
4018    cz     720.00     $ artificial zero-importance region with bounds out past where beam
tube measurements were made
c
4050    cz     36.3375      $ outer radius--Surface 3 - Be reflector
4051    cz     39.3375      $ outer radius--Surface 4 - Be reflector
4052    cz     42.3375      $ outer radius--Surface 5 - Be reflector
4053    cz     45.3375      $ outer radius--Surface 6 - Be reflector
4054    cz     48.3375      $ outer radius--Surface 7 - Be reflector
4055    cz     51.3375      $ outer radius--Surface 8 - Be reflector
c
c
C     --------------------------------
C     Reflector Irradiation Facilities
C     --------------------------------
c
220     pz    26.67      $ bounds for axial distribution in VXF
221     pz    22.1869    $ bounds for axial distribution in VXF
222     pz    15.00      $ bounds for axial distribution in VXF
223     pz    10.00      $ bounds for axial distribution in VXF
224     pz     5.00      $ bounds for axial distribution in VXF
225     pz     0.00      $ bounds for axial distribution in VXF
226     pz    -5.00      $ bounds for axial distribution in VXF
227     pz   -10.00      $ bounds for axial distribution in VXF
228     pz   -15.00      $ bounds for axial distribution in VXF
229     pz   -22.1869    $ bounds for axial distribution in VXF
230     pz   -26.67      $ bounds for axial distribution in VXF
c
c     Axial Surfaces for Capsule Heating 6/27/95
251     pz   +25.0
```

```
252    pz   +20.0
253    pz   +15.0
254    pz   +10.0
255    pz    +5.0
256    pz    +1.0
257    pz    -1.0
258    pz    -5.0
259    pz   -10.0
260    pz   -15.0
261    pz   -20.0
262    pz   -25.0
c
4200   c/z    3.076479  39.090375  2.22250    $ VXF-1,  radius=39.21125 cm, liner OD
4201   c/z    3.076479  39.090375  2.01168    $                             liner ID
4202   c/z    3.076479  39.090375  1.90240    $                             h2o ID
4203   c/z    3.076479  39.090375  1.77800    $                             ss  ID
4300   c/z   -3.456418  43.917957  2.22250    $ VXF-2,  radius=44.05376 cm, liner OD
4301   c/z   -3.456418  43.917957  2.01168    $                             liner ID
4400   c/z   -9.153685  38.127840  2.22250    $ VXF-3,  radius=39.21125 cm, liner OD
4401   c/z   -9.153685  38.127840  2.01168    $                             liner ID
4402   c/z   -9.153685  38.127840  1.90240    $                             h2o ID
4403   c/z   -9.153685  38.127840  1.77800    $                             ss  ID
4500   c/z  -16.858640  40.700367  2.22250    $ VXF-4,  radius=44.05376 cm, liner OD
4501   c/z  -16.858640  40.700367  2.01168    $                             liner ID
4600   c/z  -20.487822  33.433087  2.22250    $ VXF-5,  radius=39.21125 cm, liner OD
4601   c/z  -20.487822  33.433087  2.01168    $                             liner ID
4602   c/z  -20.487822  33.433087  1.90240    $                             h2o ID
4603   c/z  -20.487822  33.433087  1.77800    $                             ss  ID
4700   c/z  -30.054027  35.188744  3.81000    $ VXF-6,  radius=46.27626 cm, liner OD
4701   c/z  -30.054027  35.188744  3.59918    $                             liner ID
4800   c/z  -29.816468  25.465670  2.22250    $ VXF-7,  radius=39.21125 cm, liner OD
4801   c/z  -29.816468  25.465670  2.01168    $                             liner ID
4802   c/z  -29.816468  25.465670  1.90240    $                             h2o ID
4803   c/z  -29.816468  25.465670  1.77800    $                             ss  ID
4900   c/z  -37.562005  23.018026  2.22250    $ VXF-8,  radius=44.05376 cm, liner OD
4901   c/z  -37.562005  23.018026  2.01168    $                             liner ID
5000   c/z  -36.226471  15.005496  2.22250    $ VXF-9,  radius=39.21125 cm, liner OD
5001   c/z  -36.226471  15.005496  2.01168    $                             liner ID
5002   c/z  -36.226471  15.005496  1.90240    $                             h2o ID
5003   c/z  -36.226471  15.005496  1.77800    $                             ss  ID
5100   c/z  -40.700368 -16.858644  2.22250    $ VXF-10, radius=44.05376 cm, liner OD
5101   c/z  -40.700368 -16.858644  2.01168    $                             liner ID
5200   c/z  -33.433087 -20.487822  2.22250    $ VXF-11, radius=39.21125 cm, liner OD
5201   c/z  -33.433087 -20.487822  2.01168    $                             liner ID
5202   c/z  -33.433087 -20.487822  1.90240    $                             h2o ID
5203   c/z  -33.433087 -20.487822  1.77800    $                             ss  ID
```

```
5300   c/z  -33.498742 -28.610628  2.22250   $ VXF-12, radius=44.05376 cm, liner OD
5301   c/z  -33.498742 -28.610628  2.01168   $                         liner ID
5400   c/z  -25.465670 -29.816468  2.22250   $ VXF-13, radius=39.21125 cm, liner OD
5401   c/z  -25.465670 -29.816468  2.01168   $                         liner ID
5402   c/z  -25.465670 -29.816468  1.90240   $                         h2o ID
5403   c/z  -25.465670 -29.816468  1.77800   $                         ss  ID
5500   c/z  -24.179279 -39.456998  3.81000   $ VXF-14, radius=46.27626 cm, liner OD
5501   c/z  -24.179279 -39.456998  3.59918   $                         liner ID
5600   c/z  -15.005496 -36.226471  2.22250   $ VXF-15, radius=39.21125 cm, liner OD
5601   c/z  -15.005496 -36.226471  2.01168   $                         liner ID
5602   c/z  -15.005496 -36.226471  1.90240   $                         h2o ID
5603   c/z  -15.005496 -36.226471  1.77800   $                         ss  ID
5700   c/z  -10.802978 -44.997643  3.81000   $ VXF-16, radius=46.27626 cm, liner OD
5701   c/z  -10.802978 -44.997643  3.59918   $                         liner ID
5800   c/z   21.008982 -41.232450  3.81000   $ VXF-17, radius=46.27626 cm, liner OD
5801   c/z   21.008982 -41.232450  3.59918   $                         liner ID
5900   c/z   23.047795 -31.722568  2.22250   $ VXF-18, radius=39.21125 cm, liner OD
5901   c/z   23.047795 -31.722568  2.01168   $                         liner ID
5902   c/z   23.047795 -31.722568  1.90240   $                         h2o ID
5903   c/z   23.047795 -31.722568  1.77800   $                         ss  ID
6000   c/z   32.722257 -32.722257  3.81000   $ VXF-19, radius=46.27626 cm, liner OD
6001   c/z   32.722257 -32.722257  3.59918   $                         liner ID
6100   c/z   31.722568 -23.047794  2.22250   $ VXF-20, radius=39.21125 cm, liner OD
6101   c/z   31.722568 -23.047794  2.01168   $                         liner ID
6102   c/z   31.722568 -23.047794  1.90240   $                         h2o ID
6103   c/z   31.722568 -23.047794  1.77800   $                         ss  ID
6200   c/z   41.232450 -21.008982  3.81000   $ VXF-21, radius=46.27626 cm, liner OD
6201   c/z   41.232450 -21.008982  3.59918   $                         liner ID
6250   c/z   37.292115 -12.116943  2.22250   $ VXF-22, radius=39.21125 cm, liner OD
6251   c/z   37.292115 -12.116943  2.01168   $                         liner ID
6252   c/z   37.292115 -12.116943  1.90240   $                         h2o ID
6253   c/z   37.292115 -12.116943  1.77800   $                         ss  ID
c
C      -----------------------
C      Horizontal Beam Tube 1:
C      -----------------------
c      These surfaces (8850-8889) for the HB-1 beam tube (and reflector liner) were updated
c      so as to be consistent with Dwgs: E-42018, E-42295, M-11537E-0HE-004-E, and M-
11537E-0HE-005-E.
8850 44   px   -6.4897   $ vertical plane where water sheath liner (skin) around HB-1 is
snubbed off
8851 44   px  -12.04722  $ vertical plane defining midpoint of sphere (Surf 8880)
corresponding to inner surface of HB-1
8853 44   px  -12.32408  $ vertical plane defining midpoint of spheres (Surfs 8881, 8882,
8883) corresponding to outer surf of
```

```
8854 44   px  -15.80642  $ used only to segment heating rate tally along beam tube (midway
between Surfs 8853 & 8856)
8855 44   px  -12.24788  $ vertical plane defining midpoint of spheres (Surfs 8864 & 8865)
corresponding to inner & outer surfaces of reflector liner
8856 44   px  -19.28876  $ vertical plane where AL liner (in Be refl) holding tip of HB-1
becomes thicker
8857 44   px  -22.77110  $ used only to segment heating rate tally along beam tube
8858 44   px  -26.25344  $ used only to segment heating rate tally along beam tube
8859 44   px  -29.73578  $ used only to segment heating rate tally along beam tube
8860 44   px  -33.21812  $ used only to segment heating rate tally along beam tube
c
8105 44    c/y   38.354 0.0  6.7605275       $ Cylindrical Al Be liner OD
c
8861 44   cx    7.62             $ outer radius of thick portion of AL liner (in Be refl) holding tip
of HB-1
8862 44   cx    7.3025           $ outer radius of thin  portion of AL liner (in Be refl) holding tip
of HB-1
8863 44   cx    6.985            $ inner radius of AL liner (in Be refl) holding tip of HB-1
8864 44   sx  -12.24788  7.3025  $ outer sph surf corresponding to tip of AL liner (in Be refl)
holding tip of HB-1
8865 44   sx  -12.24788  6.985   $ inner sph surf corresponding to tip of AL liner (in Be refl)
holding tip of HB-1
8870 44   cx    5.08             $ Inner cyl surface of HB-1 beam tube
8875 44   cx    6.35             $ Outer cyl surface of (aluminum) water sheath liner (skin)
around HB-1 tube;  now "treated" here as outer surf of beam tube
8880 44   sx  -12.04722  5.08    $ Inner sph surface of HB-1 beam tube
8881 44   sx  -12.32408  6.02996 $ Outer sph surface of the "actual" HB-1 beam tube (at base
of grooves)
8883 44   sx  -12.32408  6.35    $ Outer sph surface of (aluminum) water sheath liner (skin)
around HB-1
c
C     ------------------------------------
C     Horizontal Beam Tube 2 (Radial tube):
C     ------------------------------------
7900   cx     8.95604              $ Cylindrical void           (Diam=7.052 inches)
7903   cx    10.795                $ Cylindrical OD Al jacket    (Diam=8.5   inches)
7904   cx    11.43                 $ Cylindrical ID AL Be liner  (Diam=9.0   inches)
7905   cx    12.065                $ Cylindrical large cyl OD Al Be liner   (Diam=9.50 inches)
7906   cx    11.7475               $ Cylindrical small cyl OD Al Be liner   (Diam=9.25 inches)
c
7910   sx   -43.14426    8.95604       $ Spherical void            (Diam=7.052 inches)
7911   sx   -43.57606   10.45464       $ Spherical Al tube wall     (Diam=8.232 inches)
7913   sx   -43.57606   10.795         $ Spherical OD Al jacket     (Diam=8.5   inches)
7914   sx   -43.28142   11.43          $ Spherical ID AL Be liner   (Diam=9.0   inches)
7915   sx   -43.28142   11.7475        $ Spherical OD Al Be liner   (Diam=9.25  inches)
c
```

7920 p -35.32252 4.36245 0 $ (x1,y1,z1), (x2,y2,z2), (x3,y3,z3) define 1st of
-54.30502 6.35 -10 $ two slanted (but vert) planes bounding rect hole
-54.30502 6.35 10 $ thru the Be inserts inside HB-2
7921 p -35.32252 -4.36245 0 $ (x1,y1,z1), (x2,y2,z2), (x3,y3,z3) define 2nd of
-54.30502 -6.35 -10 $ two slanted (but vert) planes bounding rect hole
-54.30502 -6.35 10 $ thru the Be inserts inside HB-2
7924 px -54.30502 $ vert plane bounding downstream end of Be inserts inside HB-2
7925 px -74.30502 $ dummy surf used to get surface current tally inside voided beam tube
7926 px -94.30502 $ dummy surf used to get surface current tally inside voided beam tube
7927 px -114.30502 $ dummy surf used to get surface current tally inside voided beam tube
c
c Following needed for portion of HB-2 beam tube beyond the Be reflector:
c These modifications were made based on HFIR engr dwgs:
c M-11537-OH061 & M-11537-OH062 of new HB-2, and Allis Chalmers dwg 43-31-328 of vessel nozzel
7931 px -65.8038 $ Begin expansion of HB-2 (beyond Be refl)
7932 px -77.62936 $ End of expansion of HB-2 (beyond Be refl)
7933 kx -24.065137 0.0460421 -1 $ Conical expansion (inner surf)
7934 kx -25.51631 0.0717968 -1 $ Conical expansion (outer surf); slope=15 deg
7935 cx 11.49350 $ HB2 ID=9.050" in expanded section passing thru vessel (see dwg M-11537-OH062)
7936 cx 13.96365 $ HB2 OD=10.996" in expanded section passing thru vessel (see dwg M-11537-OH061)
7937 kx -245.59826 0.0197517 +1 $ Inner surf of vessel nozzel (8-deg cone, diam=12.0" at outside of nozzel, R=17.73862 cm on inner surf, see dwg 43-31-328)
7938 px -138.43 $ Outer flat edge of HB-2 vessel nozzel
7939 cx 33.17875 $ Outer diam of HB-2 vessel nozzel
c
7949 px -46.98982 $ Plane where cyl Al Be liner transitions from large to small OD
7950 px -43.28142 $ Plane at end of cyl Al Be liner where liner becomes spherical
7951 px -43.14426 $ Plane at end of cyl beam tube where inside of beam tube becomes spherical
7952 px -43.57606 $ Plane at end of cyl beam tube where outside of beam tube becomes spherical
7953 px -34.01042 $ Plane at end of beam tube where water jacket terminates
7990 sx -46.95 5.0 $ test sphere R=2.0 cm use to verify calc
c Phantom spherical shells (2) around tip of new enlarged HB-2 beam tube
7991 sx -46.95 15.655
c
c Planes used to segment the HB-2 beam tube, surrounding water, and reflector liner into "octants"
7995 p 0.0 2.41421356 1.0 0.0 $ positive if z.ge.(-2.41421356)*y

7996   p   0.0   0.41421356 1.0 0.0 $ positive if z.ge.(E-0.41421356)*y
7997   p   0.0 -0.41421356 1.0 0.0 $ positive if z.ge.(+0.41421356)*y
7998   p   0.0 -2.41421356 1.0 0.0 $ positive if z.ge.(+2.41421356)*y
7999   cx 0.005 $needed at center of tip of HB2 beam tube to uniquely define region where 4 planes come together
c
C   -------------------------------------
C   Horizontal Beam Tube 3 (2-17-99 Model):
C   -------------------------------------
8000 43   cx 5.08 $ Inner cyl surface of HB-3 beam tube
8003 43   cx 6.35 $ Outer cyl surface of (aluminum) water sheath liner (skin) around HB-3 tube; now "treated" here as outer surf of beam tube
8004 43   cx 6.985 $ Inner radius of AL liner (in Be refl) holding tip of HB-3
8005 43   cx 7.62 $ Outer radius of thick portion of AL liner (in Be refl) holding tip of HB-3
8006 43   cx 7.3025 $ Outer radius of thin portion of AL liner (in Be refl) holding tip of HB-3
8007 43   cx 4.92125 $ Artificial surf needed to distinguish heating rates near center of sph tip from those around outer ring of sph tip (same as Surf 8604 in HB1 & HB4)
c
8010 43   sx 28.07208 5.08 $ Inner sph surface of HB-3 beam tube
8011 43   sx 28.34894 6.02996 $ Outer sph surface of the "actual" HB-3 beam tube (at base of grooves)
8013 43   sx 28.34894 6.35 $ Outer sph surface of (aluminum) water sheath liner (skin) around HB-3
8014 43   sx 28.23210 6.985 $ Inner sph surf corresponding to tip of AL liner (in Be refl) holding tip of HB-3
8015 43   sx 28.23210 7.3025 $ Outer sph surf corresponding to tip of AL liner (in Be refl) holding tip of HB-3
c
8021 43   px 22.51456 $ Vertical plane where water sheath liner (skin) around HB-3 is snubbed off
8022 43   px 28.07208 $ Vertical plane defining midpoint of sphere (Surf 8010) corresponding to inner surface of HB-3
c
8050 43   px 28.23210 $ Vertical plane defining midpoint of spheres (Surfs 8014 & 8015) corresponding to inner & outer surfaces of reflector liner
c   logically, this would have been surf 8023, but use 8050 for greater consistancy with prior models
c
8024 43   px 28.34894 $ Vertical plane defining midpoint of spheres (Surfs 8011, 8012, 8013) corresponding to outer surf of
c   beam tube body (at base of axial grooves) & outer surf of water sheath liner (skin) around HB-3;
c

```
8025 43   px  32.39135   $ Used only to segment heating rate tally along beam tube (midway
between Surfs 8024 & 8026)
8026 43   px  36.43376   $ Vertical plane where AL liner (in Be refl) holding tip of HB-3
becomes thicker
8027 43   px  40.47617   $ Used only to segment heating rate tally along beam tube
8028 43   px  44.51858   $ Used only to segment heating rate tally along beam tube
c
8030 43   py  0.0                    $ divide HB3 beam tube into sextants
8031 43   p   0.0  0.577350  1.0  0.0  $ divide HB3 beam tube into sextants
8032 43   p   0.0 -0.577350  1.0  0.0  $ divide HB3 beam tube into sextants
8035 43   cx  0.005                  $ needed at center of tip of HB3 beam tube to uniquely define
region where 3 planes come together
c
c    used to segment heating rates along HB-4 beam tube
c
8551 44   px  15.240
8552 44   px  19.050
8553 44   px  22.860
8554 44   px  26.670
8555 44   px  32.004
8556 44   px  37.338
8557 44   px  42.672
c
C      -----------------------------------
C      Cold Source (Final Design, Aug 1999)
C      -----------------------------------
8601 44   sx  11.43000  4.67360  $ main LH2 sphere (inner rad)
8602 44   sx  11.55446  4.92125  $ main LH2 sphere (outer rad)
c
8603 44   cx  4.67360   $ outer cyl body of capsule (inner rad)
8604 44   cx  4.92125   $ outer cyl body of capsule (outer rad)
c
c         sq       A         B          C     D  E  F     G        XB    YB ZB
8605 244   sq  226.75060  226.75060  92.81532  0  0  0 -2184.531 15.09268  0  0  $ smaller
surf of inner ellipsoid (xbar=15.09268, ymax=3.10388, zmax=4.85143)
8606 244   sq  307.58950  307.58950 134.20050  0  0  0 -3563.268 15.24000  0  0  $ larger
surf of inner ellipsoid (xbar=15.24000, ymax=3.40360, zmax=5.15285)
c
8607 244   sx  15.09268   3.97764  $ smaller sph surf for top & bottom of inner ellipsoid
8608 244   sx  15.24000   4.27736  $ larger  sph surf for top & bottom of inner ellipsoid
c
8609 44   cx  3.97764  $ inner surf of elliptical cyl (top & bottom)
8610 44   cx  4.27736  $ outer surf of elliptical cyl (top & bottom)
c
c         sq    A       B        C      D  E  F     G     XB YB ZB
```

8611 244   sq   0.0 226.75060 92.81532 0 0 0 -2184.531 0 0 0 $ inner side surfaces of elliptical cyl; similar to Surf 8605
8612 244   sq   0.0 307.58950 134.20050 0 0 0 -3563.268 0 0 0 $ outer side surfaces of elliptical cyl; similar to Surf 8606
c
c   (x1,   y1,   z1)   (x2,   y2,   z2)   (x3,   y3,   z3) $ pts defining surf; note that order defines +/- sense
8615 244 p 22.86 -4.0386 0.634353 22.86 4.0386 0.634353 16.034317 0 4.575163 $ inner slant plane at top (+side is in +z direction)
8616 244 p 22.86 -4.0386 0.980440 22.86 4.0386 0.980440 16.034317 0 4.921250 $ outer slant plane at top (+side is in +z direction)
8617 244 p 22.86 -4.0386 -.634353 22.86 4.0386 -.634353 16.034317 0 -4.575163 $ inner slant plane on botm (+side is in +z direction)
8618 244 p 22.86 -4.0386 -.980440 22.86 4.0386 -.980440 16.034317 0 -4.921250 $ outer slant plane on botm (+side is in +z direction)
c
8620 244   px 22.86 $ vertical plane where big transition region interfaces with inlet/outlet nozzels
c
8621 44   c/x   4.0386   0.0   0.635 $ inner wet surf of shady side coolant tube (inlet?)
8622 44   c/x   4.0386   0.0   0.71501 $ outer dry surf of shady side coolant tube (inlet?)
86221 244 k/x 32.242201 4.0386 0.0   0.0109203 $ cone corresponding to flared outer surf of coolant nozzel on shady side
c
8623 44   c/x -4.0386   0.0   0.635 $ inner wet surf of sunny side coolant tube (outlet?)
8624 44   c/x -4.0386   0.0   0.71501 $ outer dry surf of sunny side coolant tube (outlet?)
86241 244 k/x 32.242201 -4.0386 0.0   0.0109203 $ cone corresponding to flared outer surf of coolant nozzel on sunny side
c
8625 44   px   11.55446 $ midplane for outer sph surf of cold source capsule & midpt of sph shell for inner surf of vacuum vessel
86251 44   px   11.43 $ midplane for inner sph surf of cold source capsule
c
86252 44   px   12.3952 $ one of two vertical planes describing axial location of aluminum ring around where forward and rear sections of capsule are joined
86253 44   px   13.335 $ one of two vertical planes describing axial location of aluminum ring around where forward and rear sections of capsule are joined
86254 44   cx   5.02031 $ outer radius of thin aluminum ring around where forward and rear sections of capsule are joined; just beyond outer radius of main capsule
c
8626 244   px   15.09268 $ midplane of smallest (innermost) ellipsoid forming inner nose of capsule; extend inner & outer elliptical tube back to this surface

c
8627 244   c/y 18.6055 0.0 2.2225 $ cyl describing extent of aluminum stress pads used to reinforce strength of inner side wall(s) of capsule
86271 244   c/x -4.2164 0.0 7.12216 $ cyl describing curvature of aluminum stress pad on shady side of capsule wall
86272 244   c/x   4.2164 0.0 7.12216 $ cyl describing curvature of aluminum stress pad on sunny side of capsule wall
c
8629 244   px   25.40 $ vertical plane between flared section of inlet/outlet nozzels and the straight-tube stub
8630 244   px   26.67 $ vertical plane at end of the straight-tube stub(s) attached to inlet/outlet nozzels
c
8700 44   py 0.0 $ divide HB4 beam tube into sectants
8701 44   p   0.0   0.577350 1.0 0.0 $ divide HB4 beam tube into sectants
8702 44   p   0.0 -0.577350 1.0 0.0 $ divide HB4 beam tube into sectants
8710 44   cx 0.005 $ needed at center of tip of HB4 beam tube to uniquely define region where 3 planes come together
c
C   --------------------------------
C   Horizontal Beam Tube 4 Aug 1999
C   --------------------------------
8800 44   cx 8.89 $ outer radius of AL skin around large-diam portion of new HB-4 beam tube; treat as outer surf of tube in model
8802 44   cx 7.27583 $ outer radius of AL forming large-diam portion of cold source vacuum vessel; interface between vac vessel & beam tube
8803 44   cx 6.71830 $ inner radius of AL forming large-diam portion of cold source vacuum vessel
c   xbar   t*t
8807 44   kx   7.62002 0.027778 $ outer conical surf of alum skin around HB-4 beam tube (transition between small & large diam); treat as outer surf of tube in model
8809 44   kx   9.90154 0.020306 $ outer conical surf of cold source vacuum vessel (transition between small & large diam); interface between vac vessel & beam tube
8810 44   kx 13.81403 0.020306 $ inner conical surf of cold source vacuum vessel (transition between small & large diam)
c
8814 44   cx 7.62000 $ outer radius of aluminum skin over the small-diam cyl portion of new HB-4 beam tube; treated as outer rad of beam tube in final model
8816 44   cx 6.18998 $ cyl interface between inner rad of HB-4 beam tube & the cold source vacuum vessel; in final design, this is a tight shrink fit
8817 44   cx 5.63245 $ cyl inner radius the cold source vacuum vessel
c
8821 44   cx 8.8900 $ outer radius of thick portion of AL liner (in Be refl) holding tip of HB-4
8822 44   cx 8.5725 $ outer radius of thin portion of AL liner (in Be refl) holding tip of HB-4

8823 44   cx 8.2550 $ inner radius of thin portion of AL liner (in Be refl) holding tip of HB-4
c
8830 44   sx 11.75766 8.5725 $ outer sph surf corresponding to tip of AL liner (in Be refl) holding tip of HB-4
8831 44   sx 11.75766 8.255 $ inner sph surf corresponding to tip of AL liner (in Be refl) holding tip of HB-4
8832 44   sx 12.07770 7.62 $ outer sph surf of aluminum skin around outside of beam tube
8833 44   sx 12.07770 7.30250 $ outer sph surf corresponding to bare tip of HB-4 beam tube; inner/outer surfs not concentric
8834 44   sx 11.75766 6.18998 $ interface between inner surf of HB-4 beam tube & outer sph surf of cold source vacuum vessel
8835 44   sx 11.55446 5.63245 $ inner sph surf of cold source vacuum vessel
c
8840 44   px 0.0 $ vertical plane thru centerline of reactor core, midway between where HB-1 and HB-4 used to be
8841 44   px   6.14680 $ vert plane used to clip off tip of HB-4 beam tube
8842 44   px 11.75766 $ vert plane containing midpt of sph shells for refl liner & shell interface between inner surf of HB-4 beam tube and vacuum vessel
8843 44   px 12.07770 $ vert plane containing midpt of sph shells for outer surf of basic HB-4 beam tube and outer surface of outer skin around it
8844 44   px 20.96516 $ vertical plane where HB-4 reflector liner becomes thicker
8845 44   px 53.34 $ vertical plane where HB-4 beam tube starts getting larger
8846 44   px 60.96 $ vertical plane where HB-4 beam tube stops getting larger
c
C   --
C   Other in-tube components way out past vessel
C   --
8900 44   px 193.04 $ start of HB-4 beam tube flange
8901 44   px 198.12 $ end of HB-4 beam tube flange; start of cold source vacuum vessel flange; start of window #1
8902 44   px 200.66 $ end of cold source vacuum vessel flange
8903 44   px 198.4375 $ end of window #1 (in vacuum vessel flange; 0.125" thick)
8904 44   px 409.575 $ start of window #2 (at end of HB-4 beam tube)
8905 44   px 409.8925 $ end   of window #2 (at end of HB-4 beam tube)
c
8910 44   cx 13.97 $ outer surface of expanded HB-4 beam tube (going thru concrete)
8911 44   cx 13.335 $ inner surface of expanded HB-4 beam tube (going thru concrete)
8912 44   cx 12.7 $ outer radius of cold source vacuum vessel flange
c
C   -----------------------------------
C   Engineering Facilities (Slant tubes)
C   -------------------------------------
c   EF-1
8210 141   cy 4.1834

```
8211 141   cy  4.8819
8212 141   cy  5.08
8213 141   cy  5.3975
8214 141   cy  5.87375
8215 141   cy  6.50875
c
c     EF-2
8230 142   cy  4.1834
8231 142   cy  4.8819
8232 142   cy  5.08
8233 142   cy  5.3975
8234 142   cy  5.87375
8235 142   cy  6.50875
c
4809   s -29.816468  25.465670 0.0 1.7
8239 142  so    4.0
c
9999     so   500.00      $ outer radius-- OUTER SPHERE
c
c     END-SURFS
c

BURN     TIME =  2.24 504
        PFRAC =    1   0
        POWER = 85
        MAT = 533 534 536   -211 -212 -213 -214 -215 -216 -217 -218 -221 -222
            -223 -224 -225 -226 -227 -228 -231 -232 -233 -234 -235 -236 -237
            -238 -241 -242 -243 -244 -245 -246 -247 -248 -251 -252 -253 -254
            -255 -256 -257 -258 -261 -262 -263 -264 -265 -266 -267 -268 -271
            -272 -273 -274 -275 -276 -277 -278 -281 -282 -283 -284 -285 -286
            -287 -288 -291 -292 -293 -294 -295 -296 -297 -298 -201 -202 -203
            -204 -205 -206 -207 -208 -311 -312 -313 -314 -315 -316 -317 -318
            -319 -321 -322 -323 -324 -325 -326 -327 -328 -329 -331 -332 -333
            -334 -335 -336 -337 -338 -339 -341 -342 -343 -344 -345 -346 -347
            -348 -349 -351 -352 -353 -354 -355 -356 -357 -358 -359 -361 -362
            -363 -364 -365 -366 -367 -368 -369 -371 -372 -373 -374 -375 -376
            -377 -378 -379 -381 -382 -383 -384 -385 -386 -387 -388 -389 -391
            -392 -393 -394 -395 -396 -397 -398 -399 -301 -302 -303 -304 -305
            -306 -307 -308 -309
        MATVOL =  0.65485 0.008825 0.01765 13.24596 19.47788 20.7346
               45.239  50.2654  55.292   29.531   37.096   99.3446
               146.084 155.5088 339.292 376.992 414.69 221.482 278.22
               99.3446 146.084 155.5088 339.292 376.992 414.69
               221.482 278.22 99.3446 146.084 155.5088 339.292
               376.992 414.69 221.482 278.22 99.3446 146.084
               155.5088 339.292 376.992 414.69 221.482 278.22
```

```
            99.3446 146.084 155.5088 339.292 376.992 414.69
            221.482 278.22 99.3446 146.084 155.5088 339.292
            376.992 414.69 221.482 278.22 99.3446 146.084
            155.5088 339.292 376.992 414.69 221.482 278.22
            99.3446 146.084 155.5088 339.292 376.992 414.69
            221.482 278.22 33.1149 48.6947 51.8363 113.097
            125.664 138.23 73.8274 92.7398 28.5204 39.584
            40.8408 85.4514 90.4778 95.5044 49.6372 50.8938
            49.8294 213.904 296.88 306.306 640.884 678.584
            716.284 372.278 381.704 373.72 213.904 296.88
            306.306 640.884 678.584 716.284 372.278 381.704
            373.72 213.904 296.88 306.306 640.884 678.584
            716.284 372.278 381.704 373.72 213.904 296.88
            306.306 640.884 678.584 716.284 372.278 381.704
            373.72 213.904 296.88 306.306 640.884 678.584
            716.284 372.278 381.704 373.72 213.904 296.88
            306.306 640.884 678.584 716.284 372.278 381.704
            373.72 213.904 296.88 306.306 640.884 678.584
            716.284 372.278 381.704 373.72 213.904 296.88
            306.306 640.884 678.584 716.284 372.278 381.704
            373.72  71.3011 98.9602 102.102 213.628 226.195
            238.761 124.093 127.235 124.573
       BOPT =   1.0 -22 1
c
c     -------------------------
c      (2)  Transformations
c     -------------------------
c
c        Region I  Transformations for Flux Trap
c      ------------------------------------------
c
tr45      4.661173   2.691130  0.0     $ PTP-1 (G-7)
tr46      0.000000   5.382260  0.0     $ PTP-2 (D-7)
tr47     -4.661173   2.691130  0.0     $ PTP-3 (A-4)
tr48     -4.661173  -2.691130  0.0     $ PTP-4 (A-1)
tr49      0.000000  -5.382260  0.0     $ PTP-5 (D-1)
tr50      4.661173  -2.691130  0.0     $ PTP-6 (G-4)
c
c                              $ A-1 = PTP
tr52     -4.388400  -0.844550  0.0     $ A-2
tr53     -4.388400   0.844550  0.0     $ A-3
c                              $ A-4 = PTP
c
tr54     -2.925600  -3.378200  0.0     $ B-1
tr55     -2.925600  -1.689100  0.0     $ B-2
tr56     -2.925600   0.000000  0.0     $ B-3
```

```
tr57     -2.925600   1.689100  0.0     $ B-4
tr58     -2.925600   3.378200  0.0     $ B-5
c
tr59     -1.462800  -4.222750  0.0     $ C-1
tr60     -1.462800  -2.533650  0.0     $ C-2
tr61     -1.462800  -0.844550  0.0     $ C-3
tr62     -1.462800   0.844550  0.0     $ C-4
tr63     -1.462800   2.533650  0.0     $ C-5
tr64     -1.462800   4.222750  0.0     $ C-6
c
c                                $ D-1 = PTP
tr65      0.000000  -3.378200  0.0     $ D-2
tr66      0.000000  -1.689100  0.0     $ D-3
tr67      0.000000   0.000000  0.0     $ D-4
tr68      0.000000   1.689100  0.0     $ D-5
tr69      0.000000   3.378200  0.0     $ D-6
c                                $ D-7 = PTP
c
tr70      1.462800  -4.222750  0.0     $ E-2
tr71      1.462800  -2.533650  0.0     $ E-3
tr72      1.462800  -0.844550  0.0     $ E-4
tr73      1.462800   0.844550  0.0     $ E-5
tr74      1.462800   2.533650  0.0     $ E-6
tr75      1.462800   4.222750  0.0     $ E-7
c
tr76      2.925600  -3.378200  0.0     $ F-3
tr77      2.925600  -1.689100  0.0     $ F-4
tr78      2.925600   0.000000  0.0     $ F-5
tr79      2.925600   1.689100  0.0     $ F-6
tr80      2.925600   3.378200  0.0     $ F-7
c
c                                $ G-4 = PTP
tr81      4.388400  -0.844550  0.0     $ G-5
tr82      4.388400   0.844550  0.0     $ G-6
c                                $ G-4 = PTP
c
c        Region IV  Transformations for Control Element Region
c      -------------------------------------------------------
c
tr35     15.859584  28.031720  0.0     $ CR-1,   radius=32.2072 cm
tr36      8.607000  31.035839  0.0     $ CR-2,   radius=32.2072 cm
tr37    -28.031720  15.859584  0.0     $ CR-3,   radius=32.2072 cm
tr38    -31.035839   8.606999  0.0     $ CR-4,   radius=32.2072 cm
tr39    -15.859584 -28.031720  0.0     $ CR-5,   radius=32.2072 cm
tr40     -8.607000 -31.035839  0.0     $ CR-6,   radius=32.2072 cm
tr41     28.031720 -15.859580  0.0     $ CR-7,   radius=32.2072 cm
```

```
tr42      31.035839  -8.607000  0.0     $ CR-8,   radius=32.2072 cm
c
c         100 and 200   18.07 inch - 0.0 days - STARTUP
tr100      0.000 0.000    -45.8851     $ inner rod
tr200      0.000 0.000     45.8851     $ outer rod
c
c         101 and 201   20.09 inch - 1.0 days
tr101      0.000 0.000    -51.0286     $ inner rod
tr201      0.000 0.000     51.0286     $ outer rod
c
c         102 and 202   20.58 inch - 2.0 days
tr102      0.000 0.000    -52.2986     $ inner rod
tr202      0.000 0.000     52.2986     $ outer rod
c
c         103 and 203   20.71 inch - 3.0 days
tr103      0.000 0.000    -52.6034     $ inner rod
tr203      0.000 0.000     52.6034     $ outer rod
c
c         104 and 204   20.76 inch - 4.0 days
tr104      0.000 0.000    -52.7304     $ inner rod
tr204      0.000 0.000     52.7304     $ outer rod
c
c         105 and 205   20.79 inch - 5.0 days
tr105      0.000 0.000    -52.8320     $ inner rod
tr205      0.000 0.000     52.8320     $ outer rod
c
c         106 and 206   20.84 inch - 6.0 days
tr106      0.000 0.000    -52.9336     $ inner rod
tr206      0.000 0.000     52.9336     $ outer rod
c
c         107 and 207   20.90 inch - 7.0 days
tr107      0.000 0.000    -53.0860     $ inner rod
tr207      0.000 0.000     53.0860     $ outer rod
c
c         108 and 208   20.97 inch - 8.0 days
tr108      0.000 0.000    -53.2638     $ inner rod
tr208      0.000 0.000     53.2638     $ outer rod
c
c         109 and 209   21.05 inch - 9.0 days
tr109      0.000 0.000    -53.4924     $ inner rod
tr209      0.000 0.000     53.4924     $ outer rod
c
c         110 and 210   21.17 inch - 10.0 days
tr110      0.000 0.000    -53.76545     $ inner rod
tr210      0.000 0.000     53.76545     $ outer rod
c
```

```
c        111 and 211   21.28 inch - 11.0 days
tr111     0.000 0.000    -54.0766     $ inner rod
tr211     0.000 0.000     54.0766     $ outer rod
c
c        112 and 212   21.44 inch - 12.0 days
tr112     0.000 0.000    -54.4576     $ inner rod
tr212     0.000 0.000     54.4576     $ outer rod
c
c        113 and 213   21.61 inch - 13.0 days
tr113     0.000 0.000    -54.9021     $ inner rod
tr213     0.000 0.000     54.9021     $ outer rod
c
c        114 and 214   21.78 inch - 14.0 days
tr114     0.000 0.000    -55.3466     $ inner rod
tr214     0.000 0.000     55.3466     $ outer rod
c
c        115 and 215   22.02 inch - 15.0 days
tr115     0.000 0.000    -55.9562     $ inner rod
tr215     0.000 0.000     55.9562     $ outer rod
c
c        116 and 216   22.27 inch - 16.0 days
tr116     0.000 0.000    -56.5785     $ inner rod
tr216     0.000 0.000     56.5785     $ outer rod
c
c        117 and 217   22.54 inch - 17.0 days
tr117     0.000 0.000    -57.2897     $ inner rod
tr217     0.000 0.000     57.2897     $ outer rod
c
c        118 and 218   22.85 inch - 18.0 days
tr118     0.000 0.000    -58.0644     $ inner rod
tr218     0.000 0.000     58.0644     $ outer rod
c
c        119 and 219   23.19 inch - 19.0 days
tr119     0.000 0.000    -58.9534     $ inner rod
tr219     0.000 0.000     58.9534     $ outer rod
c
c        120 and 220   23.59 inch - 20.0 days
tr120     0.000 0.000    -59.96305     $ inner rod
tr220     0.000 0.000     59.96305    $ outer rod
c
c        121 and 221   23.97 inch - 21.0 days
tr121     0.000 0.000    -61.0997     $ inner rod
tr221     0.000 0.000     61.0997     $ outer rod
c
c        122 and 222   24.56 inch - 22.0 days
tr122     0.000 0.000    -62.4459     $ inner rod
```

```
tr222     0.000 0.000     62.4459     $ outer rod
c
c        123 and 223   25.19 inch - 23.0 days
tr123     0.000 0.000    -64.0588     $ inner rod
tr223     0.000 0.000     64.0588     $ outer rod
c
c        124 and 224   25.90 inch - 24.0 days
tr124     0.000 0.000    -66.1162     $ inner rod
tr224     0.000 0.000     66.1162     $ outer rod
c
c        125 and 225   26.86 inch - 24.66666667 days
tr125     0.000 0.000    -67.7418     $ inner rod
tr225     0.000 0.000     67.7418     $ outer rod
c
c
c      Region V  Transformations for  Removable  Reflector Region
c      -----------------------------------------------------------
c
tr23       7.296944  26.311930  0.0     $ RB-1A,  radius=27.305 cm
tr24      13.445625  23.765063  0.0     $ RB-1B,  radius=27.305 cm
tr25     -12.970338  22.924995  0.0     $ RB-2,   radius=26.3398 cm
tr26     -26.311929   7.296944  0.0     $ RB-3A,  radius=27.305 cm
tr27     -23.765062  13.445625  0.0     $ RB-3B,  radius=27.305 cm
tr28     -22.924995 -12.970338  0.0     $ RB-4,   radius=26.3398 cm
tr29      -7.296944 -26.311929  0.0     $ RB-5A,  radius=27.305 cm
tr30     -13.445625 -23.765062  0.0     $ RB-5B,  radius=27.305 cm
tr31      12.970338 -22.924995  0.0     $ RB-6,   radius=26.3398 cm
tr32      26.311929  -7.296944  0.0     $ RB-7A,  radius=27.305 cm
tr33      23.765062 -13.445625  0.0     $ RB-7B,  radius=27.305 cm
tr34      22.924995  12.970388  0.0     $ RB-8,   radius=26.3398 cm
c
c
c       Region VI  Transformations for Permanent Reflector Region
c       ---------------------------------------------------------
c
*tr43  $ HB-3; (all surfs in HB-3 have been revised for this new transformation)
      23.09690  -13.33500  0.0  $ location of local origin relative to the global origin (cm);
local origin at R=26.67 cm (=10.5 inch), -30 deg
       -120  -210  90           $ degrees from global x,y,z axes to local x axis
        -30  -120  90           $ degrees from global x,y,z axes to local y axis
         90    90   0           $ degrees from global x,y,z axes to local z axis
*tr44  $ HB-1 and HB-4;  (all surfs in HB-1/HB-4 have been revised for this new
transformation)
      33.215538  19.1770  0.0  $ location of local origin relative to the global origin (cm);
local origin at R=38.354 cm (=15.1 inch), 30 deg
       -60  -150  90  $ degrees from global x,y,z axes to local x axis
```

```
       +30   -60  90  $ degrees from global x,y,z axes to local y axis
        90    90   0  $ degrees from global x,y,z axes to local z axis
c
tr51        0.0000000 0.0000000 0.0
          0.9359987 0.3520030 0.0
         -0.3520030 0.9359987 0.0
          0.0000000 0.0000000 1.0     $ Planes for the gaps in the control elements
c
c          Transformations for Engineering Facility Slant Tubes (EF-1,-2)
tr141   4.6110552E+01     3.0427406E+01     0.0000000E+00  $    xc,  yc,  zc;    A= 49.000
deg,     B= 33.420 deg    EF-1
        .83465565838      .55077212342      .00000000000  $    X' =        cos(B)*X +
sin(B)*Y +  (0.0)*Z
       -.36133902449      .54758338078      .75470958022  $    Y' = -cos(A)*sin(B)*X +
cos(A)*cos(B)*Y + sin(A)*Z
        .41567299807     -.62992262156      .65605902899  $    Z' =  sin(A)*sin(B)*X + -
sin(A)*cos(B)*Y + cos(A)*Z
tr142  -1.1410619E+01     5.4053749E+01     0.0000000E+00  $    xc,  yc,  zc;    A= 49.000
deg,     B=101.920 deg    EF-2
       -.20654573690      .97843694665      .00000000000  $    X' =        cos(B)*X +
sin(B)*Y +  (0.0)*Z
       -.64191239315     -.13550619559      .75470958022  $    Y' = -cos(A)*sin(B)*X +
cos(A)*cos(B)*Y + sin(A)*Z
        .73843573728      .15588204639      .65605902899  $    Z' =  sin(A)*sin(B)*X + -
sin(A)*cos(B)*Y + cos(A)*Z
c
c       --------------------------------------------------------
c       Note:  To obtain the standard 5.0000-cm-thick cold source, *tr244 (shown here) should
be
c       identical with *tr44 shown above;  to keep the design essentially the same but slide the
c       rear surfaces forward or backward (to make a thinner or thicker cold source), simply
change
c       the location of the local origin associated with *tr244 as noted there.
c
*tr244  $ used for rear (and slanted) surfaces of the cold source
       33.215538  19.1770    0.0   $ local origin at R=38.354000 cm, 30.000000 deg;
corresponds to a 5.0-cm-thick cold source (ref case)
       -60  -150  90              $ degrees from global x,y,z axes to local x axis
       +30   -60  90              $ degrees from global x,y,z axes to local y axis
        90    90   0              $ degrees from global x,y,z axes to local z axis
c       --------------------------------------------------------
c
c
c     -----------------------------
c      (3)  Material Descriptions
c     -----------------------------
```

```
c
c        Region I  Material Descriptions
c     ------------------------------------
c
c        Water below core region   - Outlet Pressure= 2.572 MPa or 358 psi
c                                  - Pressure drop= (0.758 MPa or 110 psi pressure drop)
c                                  - Outlet Temperature= 156F or 69C
c                                  - Density= 0.9794 g/cm^3
m1       1001.70c   6.59947E-02    8016.70c    3.29974E-02
mt1      lwtr.60t
c
c        Water in core region      - Avg. Density= 0.98465 g/cm^3
m2       1001.70c   6.63485E-02    8016.70c    3.31742E-02
mt2      lwtr.60t
c
c        Water above core region   - Inlet Pressure= 3.33 MPa or 468 psi
c                                  - Inlet Temperature= 120F or 49C
c                                  - Density= 0.9899 g/cm^3
m3       1001.70c   6.67022E-02    8016.70c    3.33511E-02
mt3      lwtr.60t
c
c       Aluminum in target basket area
m25      13027.70c  5.85482E-02   1001.70c  3.45716E-04  12024.70c  5.28432E-04
        12025.70c  6.68986E-05  12026.70c  7.36554E-05  14028.70c  3.20373E-04
        14029.70c  1.62219E-05  14030.70c  1.07683E-05  22046.70c  2.10131E-06
        22047.70c  1.89500E-06  22048.70c  1.87768E-05  22049.70c  1.37795E-06
        22050.70c  1.31937E-06  24050.70c  2.65258E-06  24052.70c  5.10942E-05
        24053.70c  5.79300E-06  24054.70c  1.43910E-06  25055.70c  2.21974E-05
        26054.70c  5.96144E-06  26056.70c  9.34978E-05  26057.70c  2.16039E-06
        26058.70c  2.85334E-07  29063.70c  6.04931E-05  29065.70c  2.69626E-05
c
c       Al-1100 clad of target pellets       Total =   6.03240E-02
m511     13027.70c  6.00625E-02  14028.70c  1.33983E-04  14029.70c  6.78416E-06
        14030.70c  4.50340E-06  25055.70c  7.42655E-06  26054.70c  4.27394E-06
        26056.70c  6.70314E-05  26057.70c  1.54885E-06  26058.70c  2.04565E-07
        29063.70c  2.47400E-05  29065.70c  1.10270E-05
c
c       Al for shrouded targets              Total =   6.03240E-02
m512     13027.70c  6.00625E-02  14028.70c  1.33983E-04  14029.70c  6.78416E-06
        14030.70c  4.50340E-06  25055.70c  7.42655E-06  26054.70c  4.27394E-06
        26056.70c  6.70314E-05  26057.70c  1.54885E-06  26058.70c  2.04565E-07
        29063.70c  2.47400E-05  29065.70c  1.10270E-05
c
c       Dummy solid Al targets  ( change to Al-1100) Total =   6.03240E-02
m530     13027.70c  6.00625E-02  14028.70c  1.33983E-04  14029.70c  6.78416E-06
        14030.70c  4.50340E-06  25055.70c  7.42655E-06  26054.70c  4.27394E-06
```

```
      26056.70c  6.70314E-05  26057.70c  1.54885E-06  26058.70c  2.04565E-07
      29063.70c  2.47400E-05  29065.70c  1.10270E-05
c
c
c       material for Jp-26 & Jp-27 solid SSt targets in Al holders  Total =  5.97E-02
(communication w/ Randy Hobbs 8/9/2004)
m535     13027.70c  3.22000E-02  26054.70c  1.10565E-03  26056.70c  1.73408E-02
      26057.70c  4.00680E-04  26058.70c  5.29200E-05  24050.70c  2.41425E-04
      24052.70c  4.65035E-03  24053.70c  5.27250E-04  24054.70c  1.30980E-04
      28058.70c  1.67477E-03  28060.70c  6.45012E-04  28061.70c  2.80440E-05
      28062.70c  8.92980E-05  28064.70c  2.28780E-05  25055.70c  5.53000E-04
c
c
c   Material of PTP Experiments Loading
c   -----------------------------------
c
c   PTP-1 experiments
c
c   #1    (bottom) experiment material  (s1)  Al spacer  Al-1100   Total =   5.93745E-02
m711     13027.70c  6.00625E-02  14028.70c  1.33983E-04  14029.70c  6.78416E-06
      14030.70c  4.50340E-06  25055.70c  7.42655E-06  26054.70c  4.27394E-06
      26056.70c  6.70314E-05  26057.70c  1.54885E-06  26058.70c  2.04565E-07
      29063.70c  2.47400E-05  29065.70c  1.10270E-05
c
c   # 2  experiment material  (SO3E-003) sst/Al   Total =   4.47398E-02
m712     13027.70c  0.0356263    42000.66c  0.0001731    14028.70c  2.81486E-04
      14029.70c  1.42528E-05  14030.70c  9.46120E-06  26054.70c  4.81391E-04
      26056.70c  7.55002E-03  26057.70c  1.74453E-04  26058.70c  2.30409E-05
       6000.70c  0.0004063    $ PTP1  experiment material
c
c   # 3  experiment material  (NM-634)  W   Total =   3.38204E-02
m713     74186.70c  0.0010236     8016.70c  0.0020963    13027.70c  0.0307005
c
c   # 4  experiment material  (NM-627)  W   Total =   3.36267E-02
m714     74186.70c  0.0009543     8016.70c  0.0019719    13027.70c  0.0307005
c
c   # 5  experiment material  (S2)  Mo/V  Total =   2.32122E-02
m715     23000.70c  0.0172431    42000.66c  0.0059691
c
c   # 6  experiment material  (NM-659)  Ra   Total =   3.50519E-02
m716       8016.70c 0.0000001    13027.70c  0.0350516    $ No radon cross section
c
c   # 7  experiment material  top  (T031)  SST Tensile   Total =   6.4716E-03
m717     26054.70c  0.0003916    26056.70c  0.0059279    26057.70c  0.0001345
      26058.70c  0.0000176
c
```

```
c   PTP-2 experiments
c
c   #1  (bottom) experiment material   Gr/Al     Total=5.65355-2
m721     13027.70c  0.0285703    14028.70c  4.25273E-04  14029.70c  2.15334E-05
       14030.70c  1.42941E-05  26054.70c  5.17316E-05  26056.70c  8.11345E-04
       26057.70c  1.87472E-05  26058.70c  2.47604E-06  42000.66c  0.0003489
        6000.70c  0.0262709
mt721     grph.60t
c
c   #2  experiment material   SiC/V     Total= 4.34300-2
m722     13027.70c  0.0174491    14028.70c  1.05479E-02  14029.70c  5.34085E-04
       14030.70c  3.54532E-04   6000.70c  0.0114365    26054.70c  4.70048E-05
       26056.70c  7.37211E-04  26057.70c  1.70342E-05  26058.70c  2.24980E-06
       42000.66c  0.0001735    23000.70c  0.0135674
mt722     grph.60t
c
c   #3  experiment material  (s1)  Al spacer  Al-1100   Total =   5.93745E-02
m723     13027.70c  6.00625E-02  14028.70c  1.33983E-04  14029.70c  6.78416E-06
       14030.70c  4.50340E-06  25055.70c  7.42655E-06  26054.70c  4.27394E-06
       26056.70c  6.70314E-05  26057.70c  1.54885E-06  26058.70c  2.04565E-07
       29063.70c  2.47400E-05  29065.70c  1.10270E-05
c
c   #4  experiment material   Gr/V     Total=5.89491-2
m724     13027.70c  0.0175354    14028.70c  4.33942E-04  14029.70c  2.19724E-05
       14030.70c  1.45855E-05  26054.70c  5.14742E-05  26056.70c  8.07308E-04
       26057.70c  1.86539E-05  26058.70c  2.46372E-06  42000.66c  0.0003048
        6000.70c  0.0262254    23000.70c  0.0135332
mt724     grph.60t
c
c   #5  experiment material   Gr/V     Total=5.89252-2
m725     13027.70c  0.0174621    14028.70c  4.32374E-04  14029.70c  2.18930E-05
       14030.70c  1.45328E-05  26054.70c  5.13221E-05  26056.70c  8.04923E-04
       26057.70c  1.85988E-05  26058.70c  2.45644E-06  42000.66c  0.0003574
        6000.70c  0.0262644    23000.70c  0.0134952
mt725     grph.60t
c
c   #6  experiment material  (s1)   Al spacer  Al-1100   Total =   5.93745E-02
m726     13027.70c  6.00625E-02  14028.70c  1.33983E-04  14029.70c  6.78416E-06
       14030.70c  4.50340E-06  25055.70c  7.42655E-06  26054.70c  4.27394E-06
       26056.70c  6.70314E-05  26057.70c  1.54885E-06  26058.70c  2.04565E-07
       29063.70c  2.47400E-05  29065.70c  1.10270E-05
c
c   #7  experiment material   Gr/V     Total=6.03159-2
m727     13027.70c  0.0174755    14028.70c  4.32651E-04  14029.70c  2.19070E-05
       14030.70c  1.45421E-05  26054.70c  5.20650E-05  26056.70c  8.16575E-04
       26057.70c  1.88680E-05  26058.70c  2.49200E-06  42000.66c  0.0003404
```

```
         6000.70c  0.0263554    23000.70c  0.0147856
mt727     grph.60t
c
c   PTP-3 experiments
c
c   #1  (bottom) experiment material   Gr/Al     Total=5.64033-2
m731     13027.70c  0.0285244    14028.70c  4.32374E-04  14029.70c  2.18930E-05
        14030.70c  1.45328E-05  26054.70c  5.22932E-05  26056.70c  8.20153E-04
        26057.70c  1.89507E-05  26058.70c  2.50292E-06  42000.66c  0.0003567
         6000.70c  0.0261596
mt731     grph.60t
c
c   #2  experiment material   SiC/V     Total= 4.31828-2
m732     13027.70c  0.0174491    14028.70c  1.03287E-02  14029.70c  5.22989E-04
        14030.70c  3.47166E-04   6000.70c  0.0111989    26054.70c  4.70048E-05
        26056.70c  7.37211E-04  26057.70c  1.70342E-05  26058.70c  2.24980E-06
        42000.66c  0.0001735    23000.70c  0.0135579
mt732     grph.60t
c
c   #3 experiment material  (s1)  Al spacer  Al-1100   Total =   5.93745E-02
m733     13027.70c  6.00625E-02  14028.70c  1.33983E-04  14029.70c  6.78416E-06
        14030.70c  4.50340E-06  25055.70c  7.42655E-06  26054.70c  4.27394E-06
        26056.70c  6.70314E-05  26057.70c  1.54885E-06  26058.70c  2.04565E-07
        29063.70c  2.47400E-05  29065.70c  1.10270E-05
c
c  #4  experiment material  (S4)  Mo/V  Total =   2.59550E-02
m734     23000.70c  0.0199828    42000.66c  0.0059722
c
c  #5  experiment material  (S4)  Mo/V  Total =   2.32314E-02
m735     23000.70c  0.0172623    42000.66c  0.0059691
c
c   #6  experiment material  (s1)  Al spacer  Al-1100   Total =   5.93745E-02
m736     13027.70c  6.00625E-02  14028.70c  1.33983E-04  14029.70c  6.78416E-06
        14030.70c  4.50340E-06  25055.70c  7.42655E-06  26054.70c  4.27394E-06
        26056.70c  6.70314E-05  26057.70c  1.54885E-06  26058.70c  2.04565E-07
        29063.70c  2.47400E-05  29065.70c  1.10270E-05
c
c   #7  experiment material   Gr/V     Total=5.98973-2
m737     13027.70c  0.0174177    14028.70c  4.25641E-04  14029.70c  2.15521E-05
        14030.70c  1.43065E-05  26054.70c  5.18954E-05  26056.70c  8.13914E-04
        26057.70c  1.88065E-05  26058.70c  2.48388E-06  42000.66c  0.0003417
         6000.70c  0.0260117    23000.70c  0.0147777
mt737      grph.60t
c
c   PTP-4 experiments
c
```

```
c   #1  (bottom) experiment material   Gr/Al     Total=8.16415-2
c
m741      6000.70c  0.0430656    13027.70c  0.0361430    14028.70c  2.24386E-03
        14029.70c  1.13616E-04  14030.70c  7.54199E-05
mt741     grph.60t
c
c   #2  experiment material   SiC/V     Total= 4.31234-2
m742     13027.70c  0.0174491    14028.70c  1.02171E-02  14029.70c  5.17333E-04
        14030.70c  3.43412E-04   6000.70c  0.0110778    26054.70c  4.70048E-05
        26056.70c  7.37211E-04  26057.70c  1.70342E-05  26058.70c  2.24980E-06
        42000.66c  0.0001735    23000.70c  0.0136196
mt742     grph.60t
c
c  #3  experiment material  (s1)  Al spacer  Al-1100   Total =   5.93745E-02
m743     13027.70c  6.00625E-02  14028.70c  1.33983E-04  14029.70c  6.78416E-06
        14030.70c  4.50340E-06  25055.70c  7.42655E-06  26054.70c  4.27394E-06
        26056.70c  6.70314E-05  26057.70c  1.54885E-06  26058.70c  2.04565E-07
        29063.70c  2.47400E-05  29065.70c  1.10270E-05
c
c  #4  experiment material  (S4)  Mo/Al  Total =   4.89927E-02
m744     13027.70c  0.0432115    26054.70c  1.29402E-05  26056.70c  2.02951E-04
        26057.70c  4.68944E-06  26058.70c  6.19360E-07  42000.66c  0.0055599
c
c  #5  experiment material  (S4)  Mo/Al  Total =   4.90794E-02
m745     13027.70c  0.0433322    26054.70c  1.29402E-05  26056.70c  2.02951E-04
        26057.70c  4.68944E-06  26058.70c  6.19360E-07  42000.66c  0.0055260
c
c  #6  experiment material  (s-23)  Al spacer  Al-1100   Total =   5.93745E-02
m746     13027.70c  6.00625E-02  14028.70c  1.33983E-04  14029.70c  6.78416E-06
        14030.70c  4.50340E-06  25055.70c  7.42655E-06  26054.70c  4.27394E-06
        26056.70c  6.70314E-05  26057.70c  1.54885E-06  26058.70c  2.04565E-07
        29063.70c  2.47400E-05  29065.70c  1.10270E-05
c
c   #7  experiment material   Gr/V     Total=5.98063-2
m747     13027.70c  0.0175022    14028.70c  4.25273E-04  14029.70c  2.15334E-05
        14030.70c  1.42941E-05  26054.70c  5.17199E-05  26056.70c  8.11162E-04
        26057.70c  1.87429E-05  26058.70c  2.47548E-06  42000.66c  0.0003557
         6000.70c  0.0258166    23000.70c  0.0147865
mt747     grph.60t
c
c   PTP-5 experiments
c
c   #1  (bottom)  experiment material  (s-4)  Al spacer  Al-1100   Total =   5.93745E-02
m751     13027.70c  6.00625E-02  14028.70c  1.33983E-04  14029.70c  6.78416E-06
        14030.70c  4.50340E-06  25055.70c  7.42655E-06  26054.70c  4.27394E-06
        26056.70c  6.70314E-05  26057.70c  1.54885E-06  26058.70c  2.04565E-07
```

```
      29063.70c  2.47400E-05  29065.70c  1.10270E-05
c
c   #2  experiment material   SiC/V     Total= 4.32788-2
m752     13027.70c  0.0174491    14028.70c  1.04194E-02  14029.70c  5.27579E-04
      14030.70c  3.50213E-04   6000.70c  0.0112972    26054.70c  4.70048E-05
      26056.70c  7.37211E-04  26057.70c  1.70342E-05  26058.70c  2.24980E-06
      42000.66c  0.0001735    23000.70c  0.0135556
mt752     grph.60t
c
c   #3  experiment material   Lo3-106 assume equale to LO3-F7, -106)      Total= 4.74972-2
m753     13027.70c  0.0417166    26054.70c  1.29051E-05  26056.70c  2.02401E-04
      26057.70c  4.67672E-06  26058.70c  6.17680E-07  42000.66c  0.0055599
c
c   #4  experiment material  (Lo3-100)     Total =   7.00373E-02
m754     14028.70c  1.34632E-02  14029.70c  6.81699E-04  14030.70c  4.52519E-04
       6000.70c  0.0145951    13027.70c  0.0216858    23000.70c  0.0191590
c
c   #5  experiment material  (Lo3-101)     Total =   7.00373E-02
m755     14028.70c  1.34632E-02  14029.70c  6.81699E-04  14030.70c  4.52519E-04
       6000.70c  0.0145951    13027.70c  0.0216858    23000.70c  0.0191590
c
c   #6  experiment material  (s-9)  Al spacer  Al-1100   Total =   5.93745E-02
m756     13027.70c  6.00625E-02  14028.70c  1.33983E-04  14029.70c  6.78416E-06
      14030.70c  4.50340E-06  25055.70c  7.42655E-06  26054.70c  4.27394E-06
      26056.70c  6.70314E-05  26057.70c  1.54885E-06  26058.70c  2.04565E-07
      29063.70c  2.47400E-05  29065.70c  1.10270E-05
c
c   #7  experiment material   Gr/V     Total=6.00335-2
m757     13027.70c  0.0174852    14028.70c  4.32928E-04  14029.70c  2.19210E-05
      14030.70c  1.45514E-05  26054.70c  5.21879E-05  26056.70c  8.18502E-04
      26057.70c  1.89125E-05  26058.70c  2.49788E-06  42000.66c  0.0003382
       6000.70c  0.0260474    23000.70c  0.0148011
mt757     grph.60t
c
c   PTP-6 experiments
c
c   #1  (bottom) experiment material   Gr/Al     Total=5.63347-2
m761     13027.70c  0.0284792    14028.70c  4.32005E-04  14029.70c  2.18743E-05
      14030.70c  1.45204E-05  26054.70c  5.14157E-05  26056.70c  8.06391E-04
      26057.70c  1.86327E-05  26058.70c  2.46092E-06  42000.66c  0.0002991
       6000.70c  0.0262091
mt761     grph.60t
c
c   # 2  experiment material  (SO3E-001) sst/Al   Total =  4.49341E-02
m762     13027.70c  0.0358373    42000.66c  0.0001801    14028.70c  2.81486E-04
      14029.70c  1.42528E-05  14030.70c  9.46120E-06  26054.70c  4.80004E-04
```

```
       26056.70c  7.52827E-03  26057.70c  1.73950E-04  26058.70c  2.29746E-05
        6000.70c  0.0004063    $ PTP1  experiment material
c
c   # 3  experiment material  (SO3E-001) sst/Al   Total =  3.98252E-02
m763     13027.70c  0.0353814    42000.66c  0.0001730    14028.70c  2.81486E-04
       14029.70c  1.42528E-05  14030.70c  9.46120E-06  26054.70c  2.08219E-04
       26056.70c  3.26566E-03  26057.70c  7.54572E-05  26058.70c  9.96604E-06
        6000.70c  0.0004063    $ PTP1  experiment material
c
c   #4  experiment material   Gr/V     Total=8.80417-2
m764     14028.70c  2.24386E-03  14029.70c  1.13616E-04  14030.70c  7.54199E-05
        6000.70c  0.0430656    13027.70c  0.0253001    23000.70c  0.0172431
mt764     grph.60t
c
c   #5  experiment material   Gr/V     Total=8.80417
m765     14028.70c  2.24386E-03  14029.70c  1.13616E-04  14030.70c  7.54199E-05
        6000.70c  0.0430656    13027.70c  0.0253001    23000.70c  0.0172431
mt765     grph.60t
c
c   #6 experiment material  (s-20)  Al spacer  Al-1100   Total =   5.93745E-02
m766     13027.70c  6.00625E-02  14028.70c  1.33983E-04  14029.70c  6.78416E-06
       14030.70c  4.50340E-06  25055.70c  7.42655E-06  26054.70c  4.27394E-06
       26056.70c  6.70314E-05  26057.70c  1.54885E-06  26058.70c  2.04565E-07
       29063.70c  2.47400E-05  29065.70c  1.10270E-05
c
c   #7  experiment material   Lo3-106 assume equale to LO3-F7, -106)      Total= 4.74972-2
m767     13027.70c  0.0417166    26054.70c  1.29051E-05  26056.70c  2.02401E-04
       26057.70c  4.67672E-06  26058.70c  6.17680E-07  42000.66c  0.0055599
c
c
c        Region II ( IFE) Material Descriptions
c      ----------------------------------------
c
c     Aluminum Sidewalls
c        Aluminum fuel element sidewalls
m20      13027.70c  5.85482E-02   1001.70c  3.45716E-04  12024.70c  5.28432E-04
       12025.70c  6.68986E-05  12026.70c  7.36554E-05  14028.70c  3.20373E-04
       14029.70c  1.62219E-05  14030.70c  1.07683E-05  22046.70c  2.10131E-06
       22047.70c  1.89500E-06  22048.70c  1.87768E-05  22049.70c  1.37795E-06
       22050.70c  1.31937E-06  24050.70c  2.65258E-06  24052.70c  5.10942E-05
       24053.70c  5.79300E-06  24054.70c  1.43910E-06  25055.70c  2.21974E-05
       26054.70c  5.96144E-06  26056.70c  9.34978E-05  26057.70c  2.16039E-06
       26058.70c  2.85334E-07  29063.70c  6.04931E-05  29065.70c  2.69626E-05
c
c      Upper and lower Unfuelled Core Regions (50% H2O-50% Al-6061) *
c         Inner fuel element--lower uncontrolled region
```

```
m70      1001.70c  3.35240E-02   8016.70c  1.66756E-02  13027.70c  2.92741E-02
        14028.70c  1.60187E-04  14029.70c  8.11095E-06  14030.70c  5.38414E-06
        22046.70c  1.05065E-06  22047.70c  9.47499E-07  22048.70c  9.38839E-06
        22049.70c  6.88974E-07  22050.70c  6.59683E-07  24050.70c  1.32629E-06
        24052.70c  2.55471E-05  24053.70c  2.89649E-06  24054.70c  7.19550E-07
        25055.70c  1.10987E-05  26054.70c  2.98072E-06  26056.70c  4.67489E-05
        26057.70c  1.08019E-06  26058.70c  1.42667E-07  29063.70c  3.02466E-05
        29065.70c  1.34813E-05  12024.70c  2.64216E-04  12025.70c  3.34493E-05
        12026.70c  3.68277E-05
mt70      lwtr.60t
c       Inner fuel element--upper uncontrolled region
m71      1001.70c  3.31702E-02   8016.70c  1.64987E-02  13027.70c  2.92741E-02
        14028.70c  1.60187E-04  14029.70c  8.11095E-06  14030.70c  5.38414E-06
        22046.70c  1.05065E-06  22047.70c  9.47499E-07  22048.70c  9.38839E-06
        22049.70c  6.88974E-07  22050.70c  6.59683E-07  24050.70c  1.32629E-06
        24052.70c  2.55471E-05  24053.70c  2.89649E-06  24054.70c  7.19550E-07
        25055.70c  1.10987E-05  26054.70c  2.98072E-06  26056.70c  4.67489E-05
        26057.70c  1.08019E-06  26058.70c  1.42667E-07  29063.70c  3.02466E-05
        29065.70c  1.34813E-05  12024.70c  2.64216E-04  12025.70c  3.34493E-05
        12026.70c  3.68277E-05
mt71      lwtr.60t
c
c       Inner Fuel Element
c         unheated region material (al+h2o)/2.   6/9/95     total nd = 7.98825-2
c         used in all unfuelled regions
m200     1001.70c  3.35240E-02   8016.70c  1.66756E-02  13027.70c  2.92741E-02
        14028.70c  1.60187E-04  14029.70c  8.11095E-06  14030.70c  5.38414E-06
        22046.70c  1.05065E-06  22047.70c  9.47499E-07  22048.70c  9.38839E-06
        22049.70c  6.88974E-07  22050.70c  6.59683E-07  24050.70c  1.32629E-06
        24052.70c  2.55471E-05  24053.70c  2.89649E-06  24054.70c  7.19550E-07
        25055.70c  1.10987E-05  26054.70c  2.98072E-06  26056.70c  4.67489E-05
        26057.70c  1.08019E-06  26058.70c  1.42667E-07  29063.70c  3.02466E-05
        29065.70c  1.34813E-05  12024.70c  2.64216E-04  12025.70c  3.34493E-05
        12026.70c  3.68277E-05
mt200      lwtr.60t
c
c       Inner fuel element--fueled Axial region 1
c       total atom density =  8.00804E-02 a/b-cm
m211     $  8.008040E-02
        1001.70c 4.151254862E-01
        5010.70c 2.548951954E-04
        5011.70c 1.032582720E-03
        8016.70c 2.144807936E-01
        12024.70c 1.319749248E-03
        12025.70c 1.670784116E-04
        12026.70c 1.839527105E-04
```

```
      13027.70c 3.621274753E-01
      14028.70c 1.281762407E-03
      14029.70c 6.490092886E-05
      14030.70c 4.308197206E-05
      22046.70c 5.248003125E-06
      22047.70c 4.732745727E-06
      22048.70c 4.689489180E-05
      22049.70c 3.441417928E-06
      22050.70c 3.295102409E-06
      24050.70c 6.624807558E-06
      24052.70c 1.276080615E-04
      24053.70c 1.446796622E-05
      24054.70c 3.594151999E-06
      25055.70c 8.213386753E-05
      26054.70c 3.025198541E-05
      26056.70c 4.744646272E-04
      26057.70c 1.096311202E-05
      26058.70c 1.447957956E-06
      29063.70c 2.400126456E-04
      29065.70c 1.069770364E-04
      92234.70c 2.756081382E-05
      92235.70c 2.568669646E-03
      92236.70c 1.102440045E-05
      92238.70c 1.488279950E-04
mt211     lwtr.60t
c       total atom density =  8.00839E-02 a/b-cm
m212      $  8.008390E-02
      1001.70c 4.151070034E-01
      5010.70c 2.216587037E-04
      5011.70c 8.979417024E-04
      8016.70c 2.160895464E-01
      12024.70c 1.319690488E-03
      12025.70c 1.670709727E-04
      12026.70c 1.839445203E-04
      13027.70c 3.601072047E-01
      14028.70c 1.277222542E-03
      14029.70c 6.467115227E-05
      14030.70c 4.292946189E-05
      22046.70c 5.247769466E-06
      22047.70c 4.732535008E-06
      22048.70c 4.689280387E-05
      22049.70c 3.441264704E-06
      22050.70c 3.294955700E-06
      24050.70c 6.624512599E-06
      24052.70c 1.276023799E-04
      24053.70c 1.446732206E-05
```

24054.70c 3.593991975E-06
25055.70c 8.188234568E-05
26054.70c 3.010803809E-05
26056.70c 4.722070986E-04
26057.70c 1.091095311E-05
26058.70c 1.441063153E-06
29063.70c 2.391765753E-04
29065.70c 1.066042844E-04
92234.70c 3.362884434E-05
92235.70c 3.134211839E-03
92236.70c 1.345163763E-05
92238.70c 1.815957345E-04
mt212 lwtr.60t
c total atom density = 8.00880E-02 a/b-cm
m213 $ 8.008800E-02
1001.70c 4.150865749E-01
5010.70c 1.834372651E-04
5011.70c 7.431062827E-04
8016.70c 2.179393685E-01
12024.70c 1.319625542E-03
12025.70c 1.670627507E-04
12026.70c 1.839354679E-04
13027.70c 3.577832660E-01
14028.70c 1.272027823E-03
14029.70c 6.440800517E-05
14030.70c 4.275478875E-05
22046.70c 5.247511209E-06
22047.70c 4.732302107E-06
22048.70c 4.689049615E-05
22049.70c 3.441095350E-06
22050.70c 3.294793546E-06
24050.70c 6.624186589E-06
24052.70c 1.275961003E-04
24053.70c 1.446661008E-05
24054.70c 3.593815105E-06
25055.70c 8.159325414E-05
26054.70c 2.994248660E-05
26056.70c 4.696116853E-04
26057.70c 1.085095647E-05
26058.70c 1.433150848E-06
29063.70c 2.382158471E-04
29065.70c 1.061760028E-04
92234.70c 4.060714769E-05
92235.70c 3.784593057E-03
92236.70c 1.624303388E-05
92238.70c 2.192791469E-04

```
mt213     lwtr.60t
c       total atom density =  8.00937E-02 a/b-cm
m214   $    8.009370E-02
        1001.70c 4.150562818E-01
        5010.70c 1.295956850E-04
        5011.70c 5.249924969E-04
        8016.70c 2.205466403E-01
        12024.70c 1.319529236E-03
        12025.70c 1.670505584E-04
        12026.70c 1.839220443E-04
        13027.70c 3.545097091E-01
        14028.70c 1.264680988E-03
        14029.70c 6.403586011E-05
        14030.70c 4.250782915E-05
        22046.70c 5.247128245E-06
        22047.70c 4.731956743E-06
        22048.70c 4.688707408E-05
        22049.70c 3.440844219E-06
        22050.70c 3.294553091E-06
        24050.70c 6.623703154E-06
        24052.70c 1.275867883E-04
        24053.70c 1.446555431E-05
        24054.70c 3.593552828E-06
        25055.70c 8.118564497E-05
        26054.70c 2.970919712E-05
        26056.70c 4.659516603E-04
        26057.70c 1.076640019E-05
        26058.70c 1.421971729E-06
        29063.70c 2.368600300E-04
        29065.70c 1.055715780E-04
        92234.70c 5.043716532E-05
        92235.70c 4.700743308E-03
        92236.70c 2.017499098E-05
        92238.70c 2.723609424E-04
mt214     lwtr.60t
c       total atom density =  8.00993E-02 a/b-cm
m215     $  8.009930E-02
        1001.70c 4.150277825E-01
        5010.70c 7.715543681E-05
        5011.70c 3.125573663E-04
        8016.70c 2.230845805E-01
        12024.70c 1.319438632E-03
        12025.70c 1.670390881E-04
        12026.70c 1.839094155E-04
        13027.70c 3.513217906E-01
        14028.70c 1.257527914E-03
```

14029.70c 6.367415630E-05
14030.70c 4.226757974E-05
22046.70c 5.246767957E-06
22047.70c 4.731631829E-06
22048.70c 4.688385463E-05
22049.70c 3.440607957E-06
22050.70c 3.294326875E-06
24050.70c 6.623248346E-06
24052.70c 1.275780277E-04
24053.70c 1.446456105E-05
24054.70c 3.593306081E-06
25055.70c 8.078893055E-05
26054.70c 2.948206134E-05
26056.70c 4.623890450E-04
26057.70c 1.068408709E-05
26058.70c 1.411099954E-06
29063.70c 2.355403828E-04
29065.70c 1.049835494E-04
92234.70c 6.001132394E-05
92235.70c 5.593063481E-03
92236.70c 2.400472933E-05
92238.70c 3.240618484E-04
mt215 lwtr.60t
c total atom density = 8.00998E-02 a/b-cm
m216 $ 8.009980E-02
1001.70c 4.150249539E-01
5010.70c 7.238847983E-05
5011.70c 2.932455658E-04
8016.70c 2.233152705E-01
12024.70c 1.319429640E-03
12025.70c 1.670379497E-04
12026.70c 1.839081621E-04
13027.70c 3.510322544E-01
14028.70c 1.256882637E-03
14029.70c 6.364163735E-05
14030.70c 4.224606814E-05
22046.70c 5.246732199E-06
22047.70c 4.731599582E-06
22048.70c 4.688353511E-05
22049.70c 3.440584509E-06
22050.70c 3.294304423E-06
24050.70c 6.623203207E-06
24052.70c 1.275771582E-04
24053.70c 1.446446247E-05
24054.70c 3.593281592E-06
25055.70c 8.075279933E-05

26054.70c 2.946138595E-05
26056.70c 4.620650438E-04
26057.70c 1.067659853E-05
26058.70c 1.410116551E-06
29063.70c 2.354201754E-04
29065.70c 1.049300247E-04
92234.70c 6.088170406E-05
92235.70c 5.674174169E-03
92236.70c 2.435288137E-05
92238.70c 3.287612768E-04
mt216 lwtr.60t
c total atom density = 8.00968E-02 a/b-cm
m217 $ 8.009680E-02
1001.70c 4.150402676E-01
5010.70c 9.981758763E-05
5011.70c 4.043606908E-04
8016.70c 2.219876270E-01
12024.70c 1.319478324E-03
12025.70c 1.670441131E-04
12026.70c 1.839149480E-04
13027.70c 3.526994551E-01
14028.70c 1.260624542E-03
14029.70c 6.383050991E-05
14030.70c 4.237147708E-05
22046.70c 5.246925794E-06
22047.70c 4.731774170E-06
22048.70c 4.688526503E-05
22049.70c 3.440711460E-06
22050.70c 3.294425978E-06
24050.70c 6.623447592E-06
24052.70c 1.275818656E-04
24053.70c 1.446499618E-05
24054.70c 3.593414178E-06
25055.70c 8.096040635E-05
26054.70c 2.958020555E-05
26056.70c 4.639286088E-04
26057.70c 1.071966584E-05
26058.70c 1.415799268E-06
29063.70c 2.361117856E-04
29065.70c 1.052380285E-04
92234.70c 5.587388807E-05
92235.70c 5.207448565E-03
92236.70c 2.234970505E-05
92238.70c 3.017186460E-04
mt217 lwtr.60t
c total atom density = 8.00933E-02 a/b-cm

```
m218     $  8.009330E-02
       1001.70c 4.150582303E-01
       5010.70c 1.330435213E-04
       5011.70c 5.389586693E-04
       8016.70c 2.203791224E-01
       12024.70c 1.319535430E-03
       12025.70c 1.670513426E-04
       12026.70c 1.839229077E-04
       13027.70c 3.547198801E-01
       14028.70c 1.265148886E-03
       14029.70c 6.406013276E-05
       14030.70c 4.252388520E-05
       22046.70c 5.247152878E-06
       22047.70c 4.731978958E-06
       22048.70c 4.688729419E-05
       22049.70c 3.440860372E-06
       22050.70c 3.294568558E-06
       24050.70c 6.623734250E-06
       24052.70c 1.275873873E-04
       24053.70c 1.446562222E-05
       24054.70c 3.593569698E-06
       25055.70c 8.121174609E-05
       26054.70c 2.972406940E-05
       26056.70c 4.661860768E-04
       26057.70c 1.077181947E-05
       26058.70c 1.422690075E-06
       29063.70c 2.369472914E-04
       29065.70c 1.056105288E-04
       92234.70c 4.980776173E-05
       92235.70c 4.642083843E-03
       92236.70c 1.992325452E-05
       92238.70c 2.689611892E-04
mt218     lwtr.60t
c
c          Inner fuel element--fueled Axial region 2
c       total atom density =  8.00804E-02 a/b-cm
m221     $  8.008040E-02
       1001.70c 4.151254862E-01
       5010.70c 2.548951954E-04
       5011.70c 1.032582720E-03
       8016.70c 2.144807936E-01
       12024.70c 1.319749248E-03
       12025.70c 1.670784116E-04
       12026.70c 1.839527105E-04
       13027.70c 3.621274753E-01
       14028.70c 1.281762407E-03
```

```
      14029.70c 6.490092886E-05
      14030.70c 4.308197206E-05
      22046.70c 5.248003125E-06
      22047.70c 4.732745727E-06
      22048.70c 4.689489180E-05
      22049.70c 3.441417928E-06
      22050.70c 3.295102409E-06
      24050.70c 6.624807558E-06
      24052.70c 1.276080615E-04
      24053.70c 1.446796622E-05
      24054.70c 3.594151999E-06
      25055.70c 8.213386753E-05
      26054.70c 3.025198541E-05
      26056.70c 4.744646272E-04
      26057.70c 1.096311202E-05
      26058.70c 1.447957956E-06
      29063.70c 2.400126456E-04
      29065.70c 1.069770364E-04
      92234.70c 2.756081382E-05
      92235.70c 2.568669646E-03
      92236.70c 1.102440045E-05
      92238.70c 1.488279950E-04
mt221     lwtr.60t
c       total atom density =  8.00839E-02 a/b-cm
m222     $  8.008390E-02
      1001.70c 4.151070034E-01
      5010.70c 2.216587037E-04
      5011.70c 8.979417024E-04
      8016.70c 2.160895464E-01
      12024.70c 1.319690488E-03
      12025.70c 1.670709727E-04
      12026.70c 1.839445203E-04
      13027.70c 3.601072047E-01
      14028.70c 1.277222542E-03
      14029.70c 6.467115227E-05
      14030.70c 4.292946189E-05
      22046.70c 5.247769466E-06
      22047.70c 4.732535008E-06
      22048.70c 4.689280387E-05
      22049.70c 3.441264704E-06
      22050.70c 3.294955700E-06
      24050.70c 6.624512599E-06
      24052.70c 1.276023799E-04
      24053.70c 1.446732206E-05
      24054.70c 3.593991975E-06
      25055.70c 8.188234568E-05
```

```
        26054.70c 3.010803809E-05
        26056.70c 4.722070986E-04
        26057.70c 1.091095311E-05
        26058.70c 1.441063153E-06
        29063.70c 2.391765753E-04
        29065.70c 1.066042844E-04
        92234.70c 3.362884434E-05
        92235.70c 3.134211839E-03
        92236.70c 1.345163763E-05
        92238.70c 1.815957345E-04
mt222     lwtr.60t
c       total atom density =  8.00880E-02 a/b-cm
m223     $  8.008800E-02
        1001.70c 4.150865749E-01
        5010.70c 1.834372651E-04
        5011.70c 7.431062827E-04
        8016.70c 2.179393685E-01
        12024.70c 1.319625542E-03
        12025.70c 1.670627507E-04
        12026.70c 1.839354679E-04
        13027.70c 3.577832660E-01
        14028.70c 1.272027823E-03
        14029.70c 6.440800517E-05
        14030.70c 4.275478875E-05
        22046.70c 5.247511209E-06
        22047.70c 4.732302107E-06
        22048.70c 4.689049615E-05
        22049.70c 3.441095350E-06
        22050.70c 3.294793546E-06
        24050.70c 6.624186589E-06
        24052.70c 1.275961003E-04
        24053.70c 1.446661008E-05
        24054.70c 3.593815105E-06
        25055.70c 8.159325414E-05
        26054.70c 2.994248660E-05
        26056.70c 4.696116853E-04
        26057.70c 1.085095647E-05
        26058.70c 1.433150848E-06
        29063.70c 2.382158471E-04
        29065.70c 1.061760028E-04
        92234.70c 4.060714769E-05
        92235.70c 3.784593057E-03
        92236.70c 1.624303388E-05
        92238.70c 2.192791469E-04
mt223     lwtr.60t
c       total atom density =  8.00937E-02 a/b-cm
```

```
m224     $  8.009370E-02
        1001.70c 4.150562818E-01
        5010.70c 1.295956850E-04
        5011.70c 5.249924969E-04
        8016.70c 2.205466403E-01
        12024.70c 1.319529236E-03
        12025.70c 1.670505584E-04
        12026.70c 1.839220443E-04
        13027.70c 3.545097091E-01
        14028.70c 1.264680988E-03
        14029.70c 6.403586011E-05
        14030.70c 4.250782915E-05
        22046.70c 5.247128245E-06
        22047.70c 4.731956743E-06
        22048.70c 4.688707408E-05
        22049.70c 3.440844219E-06
        22050.70c 3.294553091E-06
        24050.70c 6.623703154E-06
        24052.70c 1.275867883E-04
        24053.70c 1.446555431E-05
        24054.70c 3.593552828E-06
        25055.70c 8.118564497E-05
        26054.70c 2.970919712E-05
        26056.70c 4.659516603E-04
        26057.70c 1.076640019E-05
        26058.70c 1.421971729E-06
        29063.70c 2.368600300E-04
        29065.70c 1.055715780E-04
        92234.70c 5.043716532E-05
        92235.70c 4.700743308E-03
        92236.70c 2.017499098E-05
        92238.70c 2.723609424E-04
mt224     lwtr.60t
c       total atom density =  8.00993E-02 a/b-cm
m225     $  8.009930E-02
        1001.70c 4.150277825E-01
        5010.70c 7.715543681E-05
        5011.70c 3.125573663E-04
        8016.70c 2.230845805E-01
        12024.70c 1.319438632E-03
        12025.70c 1.670390881E-04
        12026.70c 1.839094155E-04
        13027.70c 3.513217906E-01
        14028.70c 1.257527914E-03
        14029.70c 6.367415630E-05
        14030.70c 4.226757974E-05
```

22046.70c 5.246767957E-06
22047.70c 4.731631829E-06
22048.70c 4.688385463E-05
22049.70c 3.440607957E-06
22050.70c 3.294326875E-06
24050.70c 6.623248346E-06
24052.70c 1.275780277E-04
24053.70c 1.446456105E-05
24054.70c 3.593306081E-06
25055.70c 8.078893055E-05
26054.70c 2.948206134E-05
26056.70c 4.623890450E-04
26057.70c 1.068408709E-05
26058.70c 1.411099954E-06
29063.70c 2.355403828E-04
29065.70c 1.049835494E-04
92234.70c 6.001132394E-05
92235.70c 5.593063481E-03
92236.70c 2.400472933E-05
92238.70c 3.240618484E-04

```
mt225     lwtr.60t
c       total atom density =  8.00998E-02 a/b-cm
m226     $  8.009980E-02
        1001.70c 4.150249539E-01
        5010.70c 7.238847983E-05
        5011.70c 2.932455658E-04
        8016.70c 2.233152705E-01
        12024.70c 1.319429640E-03
        12025.70c 1.670379497E-04
        12026.70c 1.839081621E-04
        13027.70c 3.510322544E-01
        14028.70c 1.256882637E-03
        14029.70c 6.364163735E-05
        14030.70c 4.224606814E-05
        22046.70c 5.246732199E-06
        22047.70c 4.731599582E-06
        22048.70c 4.688353511E-05
        22049.70c 3.440584509E-06
        22050.70c 3.294304423E-06
        24050.70c 6.623203207E-06
        24052.70c 1.275771582E-04
        24053.70c 1.446446247E-05
        24054.70c 3.593281592E-06
        25055.70c 8.075279933E-05
        26054.70c 2.946138595E-05
        26056.70c 4.620650438E-04
```

```
        26057.70c 1.067659853E-05
        26058.70c 1.410116551E-06
        29063.70c 2.354201754E-04
        29065.70c 1.049300247E-04
        92234.70c 6.088170406E-05
        92235.70c 5.674174169E-03
        92236.70c 2.435288137E-05
        92238.70c 3.287612768E-04
mt226     lwtr.60t
c       total atom density =  8.00968E-02 a/b-cm
m227     $  8.009680E-02
        1001.70c 4.150402676E-01
        5010.70c 9.981758763E-05
        5011.70c 4.043606908E-04
        8016.70c 2.219876270E-01
        12024.70c 1.319478324E-03
        12025.70c 1.670441131E-04
        12026.70c 1.839149480E-04
        13027.70c 3.526994551E-01
        14028.70c 1.260624542E-03
        14029.70c 6.383050991E-05
        14030.70c 4.237147708E-05
        22046.70c 5.246925794E-06
        22047.70c 4.731774170E-06
        22048.70c 4.688526503E-05
        22049.70c 3.440711460E-06
        22050.70c 3.294425978E-06
        24050.70c 6.623447592E-06
        24052.70c 1.275818656E-04
        24053.70c 1.446499618E-05
        24054.70c 3.593414178E-06
        25055.70c 8.096040635E-05
        26054.70c 2.958020555E-05
        26056.70c 4.639286088E-04
        26057.70c 1.071966584E-05
        26058.70c 1.415799268E-06
        29063.70c 2.361117856E-04
        29065.70c 1.052380285E-04
        92234.70c 5.587388807E-05
        92235.70c 5.207448565E-03
        92236.70c 2.234970505E-05
        92238.70c 3.017186460E-04
mt227     lwtr.60t
c       total atom density =  8.00933E-02 a/b-cm
m228     $  8.009330E-02
        1001.70c 4.150582303E-01
```

```
       5010.70c 1.330435213E-04
       5011.70c 5.389586693E-04
       8016.70c 2.203791224E-01
       12024.70c 1.319535430E-03
       12025.70c 1.670513426E-04
       12026.70c 1.839229077E-04
       13027.70c 3.547198801E-01
       14028.70c 1.265148886E-03
       14029.70c 6.406013276E-05
       14030.70c 4.252388520E-05
       22046.70c 5.247152878E-06
       22047.70c 4.731978958E-06
       22048.70c 4.688729419E-05
       22049.70c 3.440860372E-06
       22050.70c 3.294568558E-06
       24050.70c 6.623734250E-06
       24052.70c 1.275873873E-04
       24053.70c 1.446562222E-05
       24054.70c 3.593569698E-06
       25055.70c 8.121174609E-05
       26054.70c 2.972406940E-05
       26056.70c 4.661860768E-04
       26057.70c 1.077181947E-05
       26058.70c 1.422690075E-06
       29063.70c 2.369472914E-04
       29065.70c 1.056105288E-04
       92234.70c 4.980776173E-05
       92235.70c 4.642083843E-03
       92236.70c 1.992325452E-05
       92238.70c 2.689611892E-04
mt228     lwtr.60t
c
c          Inner fuel element--fueled Axial region 3
c       total atom density =  8.00804E-02 a/b-cm
m231     $  8.008040E-02
       1001.70c 4.151254862E-01
       5010.70c 2.548951954E-04
       5011.70c 1.032582720E-03
       8016.70c 2.144807936E-01
       12024.70c 1.319749248E-03
       12025.70c 1.670784116E-04
       12026.70c 1.839527105E-04
       13027.70c 3.621274753E-01
       14028.70c 1.281762407E-03
       14029.70c 6.490092886E-05
       14030.70c 4.308197206E-05
```

```
        22046.70c 5.248003125E-06
        22047.70c 4.732745727E-06
        22048.70c 4.689489180E-05
        22049.70c 3.441417928E-06
        22050.70c 3.295102409E-06
        24050.70c 6.624807558E-06
        24052.70c 1.276080615E-04
        24053.70c 1.446796622E-05
        24054.70c 3.594151999E-06
        25055.70c 8.213386753E-05
        26054.70c 3.025198541E-05
        26056.70c 4.744646272E-04
        26057.70c 1.096311202E-05
        26058.70c 1.447957956E-06
        29063.70c 2.400126456E-04
        29065.70c 1.069770364E-04
        92234.70c 2.756081382E-05
        92235.70c 2.568669646E-03
        92236.70c 1.102440045E-05
        92238.70c 1.488279950E-04
mt231     lwtr.60t
c       total atom density =  8.00839E-02 a/b-cm
m232     $  8.008390E-02
        1001.70c 4.151070034E-01
        5010.70c 2.216587037E-04
        5011.70c 8.979417024E-04
        8016.70c 2.160895464E-01
        12024.70c 1.319690488E-03
        12025.70c 1.670709727E-04
        12026.70c 1.839445203E-04
        13027.70c 3.601072047E-01
        14028.70c 1.277222542E-03
        14029.70c 6.467115227E-05
        14030.70c 4.292946189E-05
        22046.70c 5.247769466E-06
        22047.70c 4.732535008E-06
        22048.70c 4.689280387E-05
        22049.70c 3.441264704E-06
        22050.70c 3.294955700E-06
        24050.70c 6.624512599E-06
        24052.70c 1.276023799E-04
        24053.70c 1.446732206E-05
        24054.70c 3.593991975E-06
        25055.70c 8.188234568E-05
        26054.70c 3.010803809E-05
        26056.70c 4.722070986E-04
```

```
        26057.70c 1.091095311E-05
        26058.70c 1.441063153E-06
        29063.70c 2.391765753E-04
        29065.70c 1.066042844E-04
        92234.70c 3.362884434E-05
        92235.70c 3.134211839E-03
        92236.70c 1.345163763E-05
        92238.70c 1.815957345E-04
mt232     lwtr.60t
c       total atom density =  8.00880E-02 a/b-cm
m233     $  8.008800E-02
        1001.70c 4.150865749E-01
        5010.70c 1.834372651E-04
        5011.70c 7.431062827E-04
        8016.70c 2.179393685E-01
        12024.70c 1.319625542E-03
        12025.70c 1.670627507E-04
        12026.70c 1.839354679E-04
        13027.70c 3.577832660E-01
        14028.70c 1.272027823E-03
        14029.70c 6.440800517E-05
        14030.70c 4.275478875E-05
        22046.70c 5.247511209E-06
        22047.70c 4.732302107E-06
        22048.70c 4.689049615E-05
        22049.70c 3.441095350E-06
        22050.70c 3.294793546E-06
        24050.70c 6.624186589E-06
        24052.70c 1.275961003E-04
        24053.70c 1.446661008E-05
        24054.70c 3.593815105E-06
        25055.70c 8.159325414E-05
        26054.70c 2.994248660E-05
        26056.70c 4.696116853E-04
        26057.70c 1.085095647E-05
        26058.70c 1.433150848E-06
        29063.70c 2.382158471E-04
        29065.70c 1.061760028E-04
        92234.70c 4.060714769E-05
        92235.70c 3.784593057E-03
        92236.70c 1.624303388E-05
        92238.70c 2.192791469E-04
mt233     lwtr.60t
c       total atom density =  8.00937E-02 a/b-cm
m234     $  8.009370E-02
        1001.70c 4.150562818E-01
```

```
        5010.70c 1.295956850E-04
        5011.70c 5.249924969E-04
        8016.70c 2.205466403E-01
        12024.70c 1.319529236E-03
        12025.70c 1.670505584E-04
        12026.70c 1.839220443E-04
        13027.70c 3.545097091E-01
        14028.70c 1.264680988E-03
        14029.70c 6.403586011E-05
        14030.70c 4.250782915E-05
        22046.70c 5.247128245E-06
        22047.70c 4.731956743E-06
        22048.70c 4.688707408E-05
        22049.70c 3.440844219E-06
        22050.70c 3.294553091E-06
        24050.70c 6.623703154E-06
        24052.70c 1.275867883E-04
        24053.70c 1.446555431E-05
        24054.70c 3.593552828E-06
        25055.70c 8.118564497E-05
        26054.70c 2.970919712E-05
        26056.70c 4.659516603E-04
        26057.70c 1.076640019E-05
        26058.70c 1.421971729E-06
        29063.70c 2.368600300E-04
        29065.70c 1.055715780E-04
        92234.70c 5.043716532E-05
        92235.70c 4.700743308E-03
        92236.70c 2.017499098E-05
        92238.70c 2.723609424E-04
mt234     lwtr.60t
c       total atom density =  8.00993E-02 a/b-cm
m235     $  8.009930E-02
        1001.70c 4.150277825E-01
        5010.70c 7.715543681E-05
        5011.70c 3.125573663E-04
        8016.70c 2.230845805E-01
        12024.70c 1.319438632E-03
        12025.70c 1.670390881E-04
        12026.70c 1.839094155E-04
        13027.70c 3.513217906E-01
        14028.70c 1.257527914E-03
        14029.70c 6.367415630E-05
        14030.70c 4.226757974E-05
        22046.70c 5.246767957E-06
        22047.70c 4.731631829E-06
```

22048.70c 4.688385463E-05
22049.70c 3.440607957E-06
22050.70c 3.294326875E-06
24050.70c 6.623248346E-06
24052.70c 1.275780277E-04
24053.70c 1.446456105E-05
24054.70c 3.593306081E-06
25055.70c 8.078893055E-05
26054.70c 2.948206134E-05
26056.70c 4.623890450E-04
26057.70c 1.068408709E-05
26058.70c 1.411099954E-06
29063.70c 2.355403828E-04
29065.70c 1.049835494E-04
92234.70c 6.001132394E-05
92235.70c 5.593063481E-03
92236.70c 2.400472933E-05
92238.70c 3.240618484E-04
mt235 lwtr.60t
c total atom density = 8.00998E-02 a/b-cm
m236 $ 8.009980E-02
1001.70c 4.150249539E-01
5010.70c 7.238847983E-05
5011.70c 2.932455658E-04
8016.70c 2.233152705E-01
12024.70c 1.319429640E-03
12025.70c 1.670379497E-04
12026.70c 1.839081621E-04
13027.70c 3.510322544E-01
14028.70c 1.256882637E-03
14029.70c 6.364163735E-05
14030.70c 4.224606814E-05
22046.70c 5.246732199E-06
22047.70c 4.731599582E-06
22048.70c 4.688353511E-05
22049.70c 3.440584509E-06
22050.70c 3.294304423E-06
24050.70c 6.623203207E-06
24052.70c 1.275771582E-04
24053.70c 1.446446247E-05
24054.70c 3.593281592E-06
25055.70c 8.075279933E-05
26054.70c 2.946138595E-05
26056.70c 4.620650438E-04
26057.70c 1.067659853E-05
26058.70c 1.410116551E-06

```
        29063.70c 2.354201754E-04
        29065.70c 1.049300247E-04
        92234.70c 6.088170406E-05
        92235.70c 5.674174169E-03
        92236.70c 2.435288137E-05
        92238.70c 3.287612768E-04
mt236     lwtr.60t
c       total atom density =  8.00968E-02 a/b-cm
m237     $  8.009680E-02
        1001.70c 4.150402676E-01
        5010.70c 9.981758763E-05
        5011.70c 4.043606908E-04
        8016.70c 2.219876270E-01
        12024.70c 1.319478324E-03
        12025.70c 1.670441131E-04
        12026.70c 1.839149480E-04
        13027.70c 3.526994551E-01
        14028.70c 1.260624542E-03
        14029.70c 6.383050991E-05
        14030.70c 4.237147708E-05
        22046.70c 5.246925794E-06
        22047.70c 4.731774170E-06
        22048.70c 4.688526503E-05
        22049.70c 3.440711460E-06
        22050.70c 3.294425978E-06
        24050.70c 6.623447592E-06
        24052.70c 1.275818656E-04
        24053.70c 1.446499618E-05
        24054.70c 3.593414178E-06
        25055.70c 8.096040635E-05
        26054.70c 2.958020555E-05
        26056.70c 4.639286088E-04
        26057.70c 1.071966584E-05
        26058.70c 1.415799268E-06
        29063.70c 2.361117856E-04
        29065.70c 1.052380285E-04
        92234.70c 5.587388807E-05
        92235.70c 5.207448565E-03
        92236.70c 2.234970505E-05
        92238.70c 3.017186460E-04
mt237     lwtr.60t
c       total atom density =  8.00933E-02 a/b-cm
m238     $  8.009330E-02
        1001.70c 4.150582303E-01
        5010.70c 1.330435213E-04
        5011.70c 5.389586693E-04
```

```
        8016.70c 2.203791224E-01
        12024.70c 1.319535430E-03
        12025.70c 1.670513426E-04
        12026.70c 1.839229077E-04
        13027.70c 3.547198801E-01
        14028.70c 1.265148886E-03
        14029.70c 6.406013276E-05
        14030.70c 4.252388520E-05
        22046.70c 5.247152878E-06
        22047.70c 4.731978958E-06
        22048.70c 4.688729419E-05
        22049.70c 3.440860372E-06
        22050.70c 3.294568558E-06
        24050.70c 6.623734250E-06
        24052.70c 1.275873873E-04
        24053.70c 1.446562222E-05
        24054.70c 3.593569698E-06
        25055.70c 8.121174609E-05
        26054.70c 2.972406940E-05
        26056.70c 4.661860768E-04
        26057.70c 1.077181947E-05
        26058.70c 1.422690075E-06
        29063.70c 2.369472914E-04
        29065.70c 1.056105288E-04
        92234.70c 4.980776173E-05
        92235.70c 4.642083843E-03
        92236.70c 1.992325452E-05
        92238.70c 2.689611892E-04
mt238     lwtr.60t
c
c          Inner fuel element--fueled Axial region 4
c       total atom density =  8.00804E-02 a/b-cm
m241     $  8.008040E-02
        1001.70c 4.151254862E-01
        5010.70c 2.548951954E-04
        5011.70c 1.032582720E-03
        8016.70c 2.144807936E-01
        12024.70c 1.319749248E-03
        12025.70c 1.670784116E-04
        12026.70c 1.839527105E-04
        13027.70c 3.621274753E-01
        14028.70c 1.281762407E-03
        14029.70c 6.490092886E-05
        14030.70c 4.308197206E-05
        22046.70c 5.248003125E-06
        22047.70c 4.732745727E-06
```

```
        22048.70c 4.689489180E-05
        22049.70c 3.441417928E-06
        22050.70c 3.295102409E-06
        24050.70c 6.624807558E-06
        24052.70c 1.276080615E-04
        24053.70c 1.446796622E-05
        24054.70c 3.594151999E-06
        25055.70c 8.213386753E-05
        26054.70c 3.025198541E-05
        26056.70c 4.744646272E-04
        26057.70c 1.096311202E-05
        26058.70c 1.447957956E-06
        29063.70c 2.400126456E-04
        29065.70c 1.069770364E-04
        92234.70c 2.756081382E-05
        92235.70c 2.568669646E-03
        92236.70c 1.102440045E-05
        92238.70c 1.488279950E-04
mt241     lwtr.60t
c       total atom density =  8.00839E-02 a/b-cm
m242     $  8.008390E-02
        1001.70c 4.151070034E-01
        5010.70c 2.216587037E-04
        5011.70c 8.979417024E-04
        8016.70c 2.160895464E-01
        12024.70c 1.319690488E-03
        12025.70c 1.670709727E-04
        12026.70c 1.839445203E-04
        13027.70c 3.601072047E-01
        14028.70c 1.277222542E-03
        14029.70c 6.467115227E-05
        14030.70c 4.292946189E-05
        22046.70c 5.247769466E-06
        22047.70c 4.732535008E-06
        22048.70c 4.689280387E-05
        22049.70c 3.441264704E-06
        22050.70c 3.294955700E-06
        24050.70c 6.624512599E-06
        24052.70c 1.276023799E-04
        24053.70c 1.446732206E-05
        24054.70c 3.593991975E-06
        25055.70c 8.188234568E-05
        26054.70c 3.010803809E-05
        26056.70c 4.722070986E-04
        26057.70c 1.091095311E-05
        26058.70c 1.441063153E-06
```

```
        29063.70c 2.391765753E-04
        29065.70c 1.066042844E-04
        92234.70c 3.362884434E-05
        92235.70c 3.134211839E-03
        92236.70c 1.345163763E-05
        92238.70c 1.815957345E-04
mt242     lwtr.60t
c       total atom density =  8.00880E-02 a/b-cm
m243     $  8.008800E-02
        1001.70c 4.150865749E-01
        5010.70c 1.834372651E-04
        5011.70c 7.431062827E-04
        8016.70c 2.179393685E-01
        12024.70c 1.319625542E-03
        12025.70c 1.670627507E-04
        12026.70c 1.839354679E-04
        13027.70c 3.577832660E-01
        14028.70c 1.272027823E-03
        14029.70c 6.440800517E-05
        14030.70c 4.275478875E-05
        22046.70c 5.247511209E-06
        22047.70c 4.732302107E-06
        22048.70c 4.689049615E-05
        22049.70c 3.441095350E-06
        22050.70c 3.294793546E-06
        24050.70c 6.624186589E-06
        24052.70c 1.275961003E-04
        24053.70c 1.446661008E-05
        24054.70c 3.593815105E-06
        25055.70c 8.159325414E-05
        26054.70c 2.994248660E-05
        26056.70c 4.696116853E-04
        26057.70c 1.085095647E-05
        26058.70c 1.433150848E-06
        29063.70c 2.382158471E-04
        29065.70c 1.061760028E-04
        92234.70c 4.060714769E-05
        92235.70c 3.784593057E-03
        92236.70c 1.624303388E-05
        92238.70c 2.192791469E-04
mt243     lwtr.60t
c       total atom density =  8.00937E-02 a/b-cm
m244     $  8.009370E-02
        1001.70c 4.150562818E-01
        5010.70c 1.295956850E-04
        5011.70c 5.249924969E-04
```

```
        8016.70c 2.205466403E-01
        12024.70c 1.319529236E-03
        12025.70c 1.670505584E-04
        12026.70c 1.839220443E-04
        13027.70c 3.545097091E-01
        14028.70c 1.264680988E-03
        14029.70c 6.403586011E-05
        14030.70c 4.250782915E-05
        22046.70c 5.247128245E-06
        22047.70c 4.731956743E-06
        22048.70c 4.688707408E-05
        22049.70c 3.440844219E-06
        22050.70c 3.294553091E-06
        24050.70c 6.623703154E-06
        24052.70c 1.275867883E-04
        24053.70c 1.446555431E-05
        24054.70c 3.593552828E-06
        25055.70c 8.118564497E-05
        26054.70c 2.970919712E-05
        26056.70c 4.659516603E-04
        26057.70c 1.076640019E-05
        26058.70c 1.421971729E-06
        29063.70c 2.368600300E-04
        29065.70c 1.055715780E-04
        92234.70c 5.043716532E-05
        92235.70c 4.700743308E-03
        92236.70c 2.017499098E-05
        92238.70c 2.723609424E-04
mt244     lwtr.60t
c       total atom density =  8.00993E-02 a/b-cm
m245     $  8.009930E-02
        1001.70c 4.150277825E-01
        5010.70c 7.715543681E-05
        5011.70c 3.125573663E-04
        8016.70c 2.230845805E-01
        12024.70c 1.319438632E-03
        12025.70c 1.670390881E-04
        12026.70c 1.839094155E-04
        13027.70c 3.513217906E-01
        14028.70c 1.257527914E-03
        14029.70c 6.367415630E-05
        14030.70c 4.226757974E-05
        22046.70c 5.246767957E-06
        22047.70c 4.731631829E-06
        22048.70c 4.688385463E-05
        22049.70c 3.440607957E-06
```

```
        22050.70c 3.294326875E-06
        24050.70c 6.623248346E-06
        24052.70c 1.275780277E-04
        24053.70c 1.446456105E-05
        24054.70c 3.593306081E-06
        25055.70c 8.078893055E-05
        26054.70c 2.948206134E-05
        26056.70c 4.623890450E-04
        26057.70c 1.068408709E-05
        26058.70c 1.411099954E-06
        29063.70c 2.355403828E-04
        29065.70c 1.049835494E-04
        92234.70c 6.001132394E-05
        92235.70c 5.593063481E-03
        92236.70c 2.400472933E-05
        92238.70c 3.240618484E-04
mt245     lwtr.60t
c       total atom density =  8.00998E-02 a/b-cm
m246     $  8.009980E-02
        1001.70c 4.150249539E-01
        5010.70c 7.238847983E-05
        5011.70c 2.932455658E-04
        8016.70c 2.233152705E-01
        12024.70c 1.319429640E-03
        12025.70c 1.670379497E-04
        12026.70c 1.839081621E-04
        13027.70c 3.510322544E-01
        14028.70c 1.256882637E-03
        14029.70c 6.364163735E-05
        14030.70c 4.224606814E-05
        22046.70c 5.246732199E-06
        22047.70c 4.731599582E-06
        22048.70c 4.688353511E-05
        22049.70c 3.440584509E-06
        22050.70c 3.294304423E-06
        24050.70c 6.623203207E-06
        24052.70c 1.275771582E-04
        24053.70c 1.446446247E-05
        24054.70c 3.593281592E-06
        25055.70c 8.075279933E-05
        26054.70c 2.946138595E-05
        26056.70c 4.620650438E-04
        26057.70c 1.067659853E-05
        26058.70c 1.410116551E-06
        29063.70c 2.354201754E-04
        29065.70c 1.049300247E-04
```

```
        92234.70c 6.088170406E-05
        92235.70c 5.674174169E-03
        92236.70c 2.435288137E-05
        92238.70c 3.287612768E-04
mt246     lwtr.60t
c       total atom density =  8.00968E-02 a/b-cm
m247     $  8.009680E-02
        1001.70c 4.150402676E-01
        5010.70c 9.981758763E-05
        5011.70c 4.043606908E-04
        8016.70c 2.219876270E-01
        12024.70c 1.319478324E-03
        12025.70c 1.670441131E-04
        12026.70c 1.839149480E-04
        13027.70c 3.526994551E-01
        14028.70c 1.260624542E-03
        14029.70c 6.383050991E-05
        14030.70c 4.237147708E-05
        22046.70c 5.246925794E-06
        22047.70c 4.731774170E-06
        22048.70c 4.688526503E-05
        22049.70c 3.440711460E-06
        22050.70c 3.294425978E-06
        24050.70c 6.623447592E-06
        24052.70c 1.275818656E-04
        24053.70c 1.446499618E-05
        24054.70c 3.593414178E-06
        25055.70c 8.096040635E-05
        26054.70c 2.958020555E-05
        26056.70c 4.639286088E-04
        26057.70c 1.071966584E-05
        26058.70c 1.415799268E-06
        29063.70c 2.361117856E-04
        29065.70c 1.052380285E-04
        92234.70c 5.587388807E-05
        92235.70c 5.207448565E-03
        92236.70c 2.234970505E-05
        92238.70c 3.017186460E-04
mt247     lwtr.60t
c       total atom density =  8.00933E-02 a/b-cm
m248     $  8.009330E-02
        1001.70c 4.150582303E-01
        5010.70c 1.330435213E-04
        5011.70c 5.389586693E-04
        8016.70c 2.203791224E-01
        12024.70c 1.319535430E-03
```

12025.70c 1.670513426E-04
12026.70c 1.839229077E-04
13027.70c 3.547198801E-01
14028.70c 1.265148886E-03
14029.70c 6.406013276E-05
14030.70c 4.252388520E-05
22046.70c 5.247152878E-06
22047.70c 4.731978958E-06
22048.70c 4.688729419E-05
22049.70c 3.440860372E-06
22050.70c 3.294568558E-06
24050.70c 6.623734250E-06
24052.70c 1.275873873E-04
24053.70c 1.446562222E-05
24054.70c 3.593569698E-06
25055.70c 8.121174609E-05
26054.70c 2.972406940E-05
26056.70c 4.661860768E-04
26057.70c 1.077181947E-05
26058.70c 1.422690075E-06
29063.70c 2.369472914E-04
29065.70c 1.056105288E-04
92234.70c 4.980776173E-05
92235.70c 4.642083843E-03
92236.70c 1.992325452E-05
92238.70c 2.689611892E-04
mt248 lwtr.60t
c
c Inner fuel element--fueled Axial region 5
c total atom density = 8.00804E-02 a/b-cm
m251 $ 8.008040E-02
1001.70c 4.151254862E-01
5010.70c 2.548951954E-04
5011.70c 1.032582720E-03
8016.70c 2.144807936E-01
12024.70c 1.319749248E-03
12025.70c 1.670784116E-04
12026.70c 1.839527105E-04
13027.70c 3.621274753E-01
14028.70c 1.281762407E-03
14029.70c 6.490092886E-05
14030.70c 4.308197206E-05
22046.70c 5.248003125E-06
22047.70c 4.732745727E-06
22048.70c 4.689489180E-05
22049.70c 3.441417928E-06

```
      22050.70c 3.295102409E-06
      24050.70c 6.624807558E-06
      24052.70c 1.276080615E-04
      24053.70c 1.446796622E-05
      24054.70c 3.594151999E-06
      25055.70c 8.213386753E-05
      26054.70c 3.025198541E-05
      26056.70c 4.744646272E-04
      26057.70c 1.096311202E-05
      26058.70c 1.447957956E-06
      29063.70c 2.400126456E-04
      29065.70c 1.069770364E-04
      92234.70c 2.756081382E-05
      92235.70c 2.568669646E-03
      92236.70c 1.102440045E-05
      92238.70c 1.488279950E-04
mt251    lwtr.60t
c      total atom density =  8.00839E-02 a/b-cm
m252     $  8.008390E-02
      1001.70c 4.151070034E-01
      5010.70c 2.216587037E-04
      5011.70c 8.979417024E-04
      8016.70c 2.160895464E-01
      12024.70c 1.319690488E-03
      12025.70c 1.670709727E-04
      12026.70c 1.839445203E-04
      13027.70c 3.601072047E-01
      14028.70c 1.277222542E-03
      14029.70c 6.467115227E-05
      14030.70c 4.292946189E-05
      22046.70c 5.247769466E-06
      22047.70c 4.732535008E-06
      22048.70c 4.689280387E-05
      22049.70c 3.441264704E-06
      22050.70c 3.294955700E-06
      24050.70c 6.624512599E-06
      24052.70c 1.276023799E-04
      24053.70c 1.446732206E-05
      24054.70c 3.593991975E-06
      25055.70c 8.188234568E-05
      26054.70c 3.010803809E-05
      26056.70c 4.722070986E-04
      26057.70c 1.091095311E-05
      26058.70c 1.441063153E-06
      29063.70c 2.391765753E-04
      29065.70c 1.066042844E-04
```

```
        92234.70c 3.362884434E-05
        92235.70c 3.134211839E-03
        92236.70c 1.345163763E-05
        92238.70c 1.815957345E-04
mt252     lwtr.60t
c       total atom density =  8.00880E-02 a/b-cm
m253     $  8.008800E-02
        1001.70c 4.150865749E-01
        5010.70c 1.834372651E-04
        5011.70c 7.431062827E-04
        8016.70c 2.179393685E-01
        12024.70c 1.319625542E-03
        12025.70c 1.670627507E-04
        12026.70c 1.839354679E-04
        13027.70c 3.577832660E-01
        14028.70c 1.272027823E-03
        14029.70c 6.440800517E-05
        14030.70c 4.275478875E-05
        22046.70c 5.247511209E-06
        22047.70c 4.732302107E-06
        22048.70c 4.689049615E-05
        22049.70c 3.441095350E-06
        22050.70c 3.294793546E-06
        24050.70c 6.624186589E-06
        24052.70c 1.275961003E-04
        24053.70c 1.446661008E-05
        24054.70c 3.593815105E-06
        25055.70c 8.159325414E-05
        26054.70c 2.994248660E-05
        26056.70c 4.696116853E-04
        26057.70c 1.085095647E-05
        26058.70c 1.433150848E-06
        29063.70c 2.382158471E-04
        29065.70c 1.061760028E-04
        92234.70c 4.060714769E-05
        92235.70c 3.784593057E-03
        92236.70c 1.624303388E-05
        92238.70c 2.192791469E-04
mt253     lwtr.60t
c       total atom density =  8.00937E-02 a/b-cm
m254     $  8.009370E-02
        1001.70c 4.150562818E-01
        5010.70c 1.295956850E-04
        5011.70c 5.249924969E-04
        8016.70c 2.205466403E-01
        12024.70c 1.319529236E-03
```

12025.70c 1.670505584E-04
12026.70c 1.839220443E-04
13027.70c 3.545097091E-01
14028.70c 1.264680988E-03
14029.70c 6.403586011E-05
14030.70c 4.250782915E-05
22046.70c 5.247128245E-06
22047.70c 4.731956743E-06
22048.70c 4.688707408E-05
22049.70c 3.440844219E-06
22050.70c 3.294553091E-06
24050.70c 6.623703154E-06
24052.70c 1.275867883E-04
24053.70c 1.446555431E-05
24054.70c 3.593552828E-06
25055.70c 8.118564497E-05
26054.70c 2.970919712E-05
26056.70c 4.659516603E-04
26057.70c 1.076640019E-05
26058.70c 1.421971729E-06
29063.70c 2.368600300E-04
29065.70c 1.055715780E-04
92234.70c 5.043716532E-05
92235.70c 4.700743308E-03
92236.70c 2.017499098E-05
92238.70c 2.723609424E-04
mt254 lwtr.60t
c total atom density = 8.00993E-02 a/b-cm
m255 $ 8.009930E-02
1001.70c 4.150277825E-01
5010.70c 7.715543681E-05
5011.70c 3.125573663E-04
8016.70c 2.230845805E-01
12024.70c 1.319438632E-03
12025.70c 1.670390881E-04
12026.70c 1.839094155E-04
13027.70c 3.513217906E-01
14028.70c 1.257527914E-03
14029.70c 6.367415630E-05
14030.70c 4.226757974E-05
22046.70c 5.246767957E-06
22047.70c 4.731631829E-06
22048.70c 4.688385463E-05
22049.70c 3.440607957E-06
22050.70c 3.294326875E-06
24050.70c 6.623248346E-06

```
        24052.70c 1.275780277E-04
        24053.70c 1.446456105E-05
        24054.70c 3.593306081E-06
        25055.70c 8.078893055E-05
        26054.70c 2.948206134E-05
        26056.70c 4.623890450E-04
        26057.70c 1.068408709E-05
        26058.70c 1.411099954E-06
        29063.70c 2.355403828E-04
        29065.70c 1.049835494E-04
        92234.70c 6.001132394E-05
        92235.70c 5.593063481E-03
        92236.70c 2.400472933E-05
        92238.70c 3.240618484E-04
mt255     lwtr.60t
c       total atom density =  8.00998E-02 a/b-cm
m256     $  8.009980E-02
        1001.70c 4.150249539E-01
        5010.70c 7.238847983E-05
        5011.70c 2.932455658E-04
        8016.70c 2.233152705E-01
        12024.70c 1.319429640E-03
        12025.70c 1.670379497E-04
        12026.70c 1.839081621E-04
        13027.70c 3.510322544E-01
        14028.70c 1.256882637E-03
        14029.70c 6.364163735E-05
        14030.70c 4.224606814E-05
        22046.70c 5.246732199E-06
        22047.70c 4.731599582E-06
        22048.70c 4.688353511E-05
        22049.70c 3.440584509E-06
        22050.70c 3.294304423E-06
        24050.70c 6.623203207E-06
        24052.70c 1.275771582E-04
        24053.70c 1.446446247E-05
        24054.70c 3.593281592E-06
        25055.70c 8.075279933E-05
        26054.70c 2.946138595E-05
        26056.70c 4.620650438E-04
        26057.70c 1.067659853E-05
        26058.70c 1.410116551E-06
        29063.70c 2.354201754E-04
        29065.70c 1.049300247E-04
        92234.70c 6.088170406E-05
        92235.70c 5.674174169E-03
```

92236.70c 2.435288137E-05
92238.70c 3.287612768E-04
mt256 lwtr.60t
c total atom density = 8.00968E-02 a/b-cm
m257 $ 8.009680E-02
1001.70c 4.150402676E-01
5010.70c 9.981758763E-05
5011.70c 4.043606908E-04
8016.70c 2.219876270E-01
12024.70c 1.319478324E-03
12025.70c 1.670441131E-04
12026.70c 1.839149480E-04
13027.70c 3.526994551E-01
14028.70c 1.260624542E-03
14029.70c 6.383050991E-05
14030.70c 4.237147708E-05
22046.70c 5.246925794E-06
22047.70c 4.731774170E-06
22048.70c 4.688526503E-05
22049.70c 3.440711460E-06
22050.70c 3.294425978E-06
24050.70c 6.623447592E-06
24052.70c 1.275818656E-04
24053.70c 1.446499618E-05
24054.70c 3.593414178E-06
25055.70c 8.096040635E-05
26054.70c 2.958020555E-05
26056.70c 4.639286088E-04
26057.70c 1.071966584E-05
26058.70c 1.415799268E-06
29063.70c 2.361117856E-04
29065.70c 1.052380285E-04
92234.70c 5.587388807E-05
92235.70c 5.207448565E-03
92236.70c 2.234970505E-05
92238.70c 3.017186460E-04
mt257 lwtr.60t
c total atom density = 8.00933E-02 a/b-cm
m258 $ 8.009330E-02
1001.70c 4.150582303E-01
5010.70c 1.330435213E-04
5011.70c 5.389586693E-04
8016.70c 2.203791224E-01
12024.70c 1.319535430E-03
12025.70c 1.670513426E-04
12026.70c 1.839229077E-04

```
        13027.70c 3.547198801E-01
        14028.70c 1.265148886E-03
        14029.70c 6.406013276E-05
        14030.70c 4.252388520E-05
        22046.70c 5.247152878E-06
        22047.70c 4.731978958E-06
        22048.70c 4.688729419E-05
        22049.70c 3.440860372E-06
        22050.70c 3.294568558E-06
        24050.70c 6.623734250E-06
        24052.70c 1.275873873E-04
        24053.70c 1.446562222E-05
        24054.70c 3.593569698E-06
        25055.70c 8.121174609E-05
        26054.70c 2.972406940E-05
        26056.70c 4.661860768E-04
        26057.70c 1.077181947E-05
        26058.70c 1.422690075E-06
        29063.70c 2.369472914E-04
        29065.70c 1.056105288E-04
        92234.70c 4.980776173E-05
        92235.70c 4.642083843E-03
        92236.70c 1.992325452E-05
        92238.70c 2.689611892E-04
mt258     lwtr.60t
c
c         Inner fuel element--fueled Axial region 6
c       total atom density =  8.00804E-02 a/b-cm
m261     $  8.008040E-02
        1001.70c 4.151254862E-01
        5010.70c 2.548951954E-04
        5011.70c 1.032582720E-03
        8016.70c 2.144807936E-01
        12024.70c 1.319749248E-03
        12025.70c 1.670784116E-04
        12026.70c 1.839527105E-04
        13027.70c 3.621274753E-01
        14028.70c 1.281762407E-03
        14029.70c 6.490092886E-05
        14030.70c 4.308197206E-05
        22046.70c 5.248003125E-06
        22047.70c 4.732745727E-06
        22048.70c 4.689489180E-05
        22049.70c 3.441417928E-06
        22050.70c 3.295102409E-06
        24050.70c 6.624807558E-06
```

```
        24052.70c 1.276080615E-04
        24053.70c 1.446796622E-05
        24054.70c 3.594151999E-06
        25055.70c 8.213386753E-05
        26054.70c 3.025198541E-05
        26056.70c 4.744646272E-04
        26057.70c 1.096311202E-05
        26058.70c 1.447957956E-06
        29063.70c 2.400126456E-04
        29065.70c 1.069770364E-04
        92234.70c 2.756081382E-05
        92235.70c 2.568669646E-03
        92236.70c 1.102440045E-05
        92238.70c 1.488279950E-04
mt261     lwtr.60t
c       total atom density =  8.00839E-02 a/b-cm
m262     $  8.008390E-02
        1001.70c 4.151070034E-01
        5010.70c 2.216587037E-04
        5011.70c 8.979417024E-04
        8016.70c 2.160895464E-01
        12024.70c 1.319690488E-03
        12025.70c 1.670709727E-04
        12026.70c 1.839445203E-04
        13027.70c 3.601072047E-01
        14028.70c 1.277222542E-03
        14029.70c 6.467115227E-05
        14030.70c 4.292946189E-05
        22046.70c 5.247769466E-06
        22047.70c 4.732535008E-06
        22048.70c 4.689280387E-05
        22049.70c 3.441264704E-06
        22050.70c 3.294955700E-06
        24050.70c 6.624512599E-06
        24052.70c 1.276023799E-04
        24053.70c 1.446732206E-05
        24054.70c 3.593991975E-06
        25055.70c 8.188234568E-05
        26054.70c 3.010803809E-05
        26056.70c 4.722070986E-04
        26057.70c 1.091095311E-05
        26058.70c 1.441063153E-06
        29063.70c 2.391765753E-04
        29065.70c 1.066042844E-04
        92234.70c 3.362884434E-05
        92235.70c 3.134211839E-03
```

```
        92236.70c 1.345163763E-05
        92238.70c 1.815957345E-04
mt262     lwtr.60t
c       total atom density =  8.00880E-02 a/b-cm
m263     $  8.008800E-02
        1001.70c 4.150865749E-01
        5010.70c 1.834372651E-04
        5011.70c 7.431062827E-04
        8016.70c 2.179393685E-01
        12024.70c 1.319625542E-03
        12025.70c 1.670627507E-04
        12026.70c 1.839354679E-04
        13027.70c 3.577832660E-01
        14028.70c 1.272027823E-03
        14029.70c 6.440800517E-05
        14030.70c 4.275478875E-05
        22046.70c 5.247511209E-06
        22047.70c 4.732302107E-06
        22048.70c 4.689049615E-05
        22049.70c 3.441095350E-06
        22050.70c 3.294793546E-06
        24050.70c 6.624186589E-06
        24052.70c 1.275961003E-04
        24053.70c 1.446661008E-05
        24054.70c 3.593815105E-06
        25055.70c 8.159325414E-05
        26054.70c 2.994248660E-05
        26056.70c 4.696116853E-04
        26057.70c 1.085095647E-05
        26058.70c 1.433150848E-06
        29063.70c 2.382158471E-04
        29065.70c 1.061760028E-04
        92234.70c 4.060714769E-05
        92235.70c 3.784593057E-03
        92236.70c 1.624303388E-05
        92238.70c 2.192791469E-04
mt263     lwtr.60t
c       total atom density =  8.00937E-02 a/b-cm
m264     $  8.009370E-02
        1001.70c 4.150562818E-01
        5010.70c 1.295956850E-04
        5011.70c 5.249924969E-04
        8016.70c 2.205466403E-01
        12024.70c 1.319529236E-03
        12025.70c 1.670505584E-04
        12026.70c 1.839220443E-04
```

```
        13027.70c 3.545097091E-01
        14028.70c 1.264680988E-03
        14029.70c 6.403586011E-05
        14030.70c 4.250782915E-05
        22046.70c 5.247128245E-06
        22047.70c 4.731956743E-06
        22048.70c 4.688707408E-05
        22049.70c 3.440844219E-06
        22050.70c 3.294553091E-06
        24050.70c 6.623703154E-06
        24052.70c 1.275867883E-04
        24053.70c 1.446555431E-05
        24054.70c 3.593552828E-06
        25055.70c 8.118564497E-05
        26054.70c 2.970919712E-05
        26056.70c 4.659516603E-04
        26057.70c 1.076640019E-05
        26058.70c 1.421971729E-06
        29063.70c 2.368600300E-04
        29065.70c 1.055715780E-04
        92234.70c 5.043716532E-05
        92235.70c 4.700743308E-03
        92236.70c 2.017499098E-05
        92238.70c 2.723609424E-04
mt264     lwtr.60t
c       total atom density =  8.00993E-02 a/b-cm
m265     $  8.009930E-02
        1001.70c 4.150277825E-01
        5010.70c 7.715543681E-05
        5011.70c 3.125573663E-04
        8016.70c 2.230845805E-01
        12024.70c 1.319438632E-03
        12025.70c 1.670390881E-04
        12026.70c 1.839094155E-04
        13027.70c 3.513217906E-01
        14028.70c 1.257527914E-03
        14029.70c 6.367415630E-05
        14030.70c 4.226757974E-05
        22046.70c 5.246767957E-06
        22047.70c 4.731631829E-06
        22048.70c 4.688385463E-05
        22049.70c 3.440607957E-06
        22050.70c 3.294326875E-06
        24050.70c 6.623248346E-06
        24052.70c 1.275780277E-04
        24053.70c 1.446456105E-05
```

```
        24054.70c 3.593306081E-06
        25055.70c 8.078893055E-05
        26054.70c 2.948206134E-05
        26056.70c 4.623890450E-04
        26057.70c 1.068408709E-05
        26058.70c 1.411099954E-06
        29063.70c 2.355403828E-04
        29065.70c 1.049835494E-04
        92234.70c 6.001132394E-05
        92235.70c 5.593063481E-03
        92236.70c 2.400472933E-05
        92238.70c 3.240618484E-04
mt265     lwtr.60t
c       total atom density =  8.00998E-02 a/b-cm
m266     $  8.009980E-02
        1001.70c 4.150249539E-01
        5010.70c 7.238847983E-05
        5011.70c 2.932455658E-04
        8016.70c 2.233152705E-01
        12024.70c 1.319429640E-03
        12025.70c 1.670379497E-04
        12026.70c 1.839081621E-04
        13027.70c 3.510322544E-01
        14028.70c 1.256882637E-03
        14029.70c 6.364163735E-05
        14030.70c 4.224606814E-05
        22046.70c 5.246732199E-06
        22047.70c 4.731599582E-06
        22048.70c 4.688353511E-05
        22049.70c 3.440584509E-06
        22050.70c 3.294304423E-06
        24050.70c 6.623203207E-06
        24052.70c 1.275771582E-04
        24053.70c 1.446446247E-05
        24054.70c 3.593281592E-06
        25055.70c 8.075279933E-05
        26054.70c 2.946138595E-05
        26056.70c 4.620650438E-04
        26057.70c 1.067659853E-05
        26058.70c 1.410116551E-06
        29063.70c 2.354201754E-04
        29065.70c 1.049300247E-04
        92234.70c 6.088170406E-05
        92235.70c 5.674174169E-03
        92236.70c 2.435288137E-05
        92238.70c 3.287612768E-04
```

```
mt266     lwtr.60t
c       total atom density =  8.00968E-02 a/b-cm
m267     $  8.009680E-02
        1001.70c 4.150402676E-01
        5010.70c 9.981758763E-05
        5011.70c 4.043606908E-04
        8016.70c 2.219876270E-01
        12024.70c 1.319478324E-03
        12025.70c 1.670441131E-04
        12026.70c 1.839149480E-04
        13027.70c 3.526994551E-01
        14028.70c 1.260624542E-03
        14029.70c 6.383050991E-05
        14030.70c 4.237147708E-05
        22046.70c 5.246925794E-06
        22047.70c 4.731774170E-06
        22048.70c 4.688526503E-05
        22049.70c 3.440711460E-06
        22050.70c 3.294425978E-06
        24050.70c 6.623447592E-06
        24052.70c 1.275818656E-04
        24053.70c 1.446499618E-05
        24054.70c 3.593414178E-06
        25055.70c 8.096040635E-05
        26054.70c 2.958020555E-05
        26056.70c 4.639286088E-04
        26057.70c 1.071966584E-05
        26058.70c 1.415799268E-06
        29063.70c 2.361117856E-04
        29065.70c 1.052380285E-04
        92234.70c 5.587388807E-05
        92235.70c 5.207448565E-03
        92236.70c 2.234970505E-05
        92238.70c 3.017186460E-04
mt267     lwtr.60t
c       total atom density =  8.00933E-02 a/b-cm
m268     $  8.009330E-02
        1001.70c 4.150582303E-01
        5010.70c 1.330435213E-04
        5011.70c 5.389586693E-04
        8016.70c 2.203791224E-01
        12024.70c 1.319535430E-03
        12025.70c 1.670513426E-04
        12026.70c 1.839229077E-04
        13027.70c 3.547198801E-01
        14028.70c 1.265148886E-03
```

14029.70c 6.406013276E-05
14030.70c 4.252388520E-05
22046.70c 5.247152878E-06
22047.70c 4.731978958E-06
22048.70c 4.688729419E-05
22049.70c 3.440860372E-06
22050.70c 3.294568558E-06
24050.70c 6.623734250E-06
24052.70c 1.275873873E-04
24053.70c 1.446562222E-05
24054.70c 3.593569698E-06
25055.70c 8.121174609E-05
26054.70c 2.972406940E-05
26056.70c 4.661860768E-04
26057.70c 1.077181947E-05
26058.70c 1.422690075E-06
29063.70c 2.369472914E-04
29065.70c 1.056105288E-04
92234.70c 4.980776173E-05
92235.70c 4.642083843E-03
92236.70c 1.992325452E-05
92238.70c 2.689611892E-04
mt268 lwtr.60t
c
c Inner fuel element--fueled Axial region 7
c total atom density = 8.00804E-02 a/b-cm
m271 $ 8.008040E-02
1001.70c 4.151254862E-01
5010.70c 2.548951954E-04
5011.70c 1.032582720E-03
8016.70c 2.144807936E-01
12024.70c 1.319749248E-03
12025.70c 1.670784116E-04
12026.70c 1.839527105E-04
13027.70c 3.621274753E-01
14028.70c 1.281762407E-03
14029.70c 6.490092886E-05
14030.70c 4.308197206E-05
22046.70c 5.248003125E-06
22047.70c 4.732745727E-06
22048.70c 4.689489180E-05
22049.70c 3.441417928E-06
22050.70c 3.295102409E-06
24050.70c 6.624807558E-06
24052.70c 1.276080615E-04
24053.70c 1.446796622E-05

```
        24054.70c 3.594151999E-06
        25055.70c 8.213386753E-05
        26054.70c 3.025198541E-05
        26056.70c 4.744646272E-04
        26057.70c 1.096311202E-05
        26058.70c 1.447957956E-06
        29063.70c 2.400126456E-04
        29065.70c 1.069770364E-04
        92234.70c 2.756081382E-05
        92235.70c 2.568669646E-03
        92236.70c 1.102440045E-05
        92238.70c 1.488279950E-04
mt271     lwtr.60t
c       total atom density =  8.00839E-02 a/b-cm
m272     $  8.008390E-02
        1001.70c 4.151070034E-01
        5010.70c 2.216587037E-04
        5011.70c 8.979417024E-04
        8016.70c 2.160895464E-01
        12024.70c 1.319690488E-03
        12025.70c 1.670709727E-04
        12026.70c 1.839445203E-04
        13027.70c 3.601072047E-01
        14028.70c 1.277222542E-03
        14029.70c 6.467115227E-05
        14030.70c 4.292946189E-05
        22046.70c 5.247769466E-06
        22047.70c 4.732535008E-06
        22048.70c 4.689280387E-05
        22049.70c 3.441264704E-06
        22050.70c 3.294955700E-06
        24050.70c 6.624512599E-06
        24052.70c 1.276023799E-04
        24053.70c 1.446732206E-05
        24054.70c 3.593991975E-06
        25055.70c 8.188234568E-05
        26054.70c 3.010803809E-05
        26056.70c 4.722070986E-04
        26057.70c 1.091095311E-05
        26058.70c 1.441063153E-06
        29063.70c 2.391765753E-04
        29065.70c 1.066042844E-04
        92234.70c 3.362884434E-05
        92235.70c 3.134211839E-03
        92236.70c 1.345163763E-05
        92238.70c 1.815957345E-04
```

```
mt272     lwtr.60t
c       total atom density =  8.00880E-02 a/b-cm
m273     $  8.008800E-02
        1001.70c 4.150865749E-01
        5010.70c 1.834372651E-04
        5011.70c 7.431062827E-04
        8016.70c 2.179393685E-01
        12024.70c 1.319625542E-03
        12025.70c 1.670627507E-04
        12026.70c 1.839354679E-04
        13027.70c 3.577832660E-01
        14028.70c 1.272027823E-03
        14029.70c 6.440800517E-05
        14030.70c 4.275478875E-05
        22046.70c 5.247511209E-06
        22047.70c 4.732302107E-06
        22048.70c 4.689049615E-05
        22049.70c 3.441095350E-06
        22050.70c 3.294793546E-06
        24050.70c 6.624186589E-06
        24052.70c 1.275961003E-04
        24053.70c 1.446661008E-05
        24054.70c 3.593815105E-06
        25055.70c 8.159325414E-05
        26054.70c 2.994248660E-05
        26056.70c 4.696116853E-04
        26057.70c 1.085095647E-05
        26058.70c 1.433150848E-06
        29063.70c 2.382158471E-04
        29065.70c 1.061760028E-04
        92234.70c 4.060714769E-05
        92235.70c 3.784593057E-03
        92236.70c 1.624303388E-05
        92238.70c 2.192791469E-04
mt273     lwtr.60t
c       total atom density =  8.00937E-02 a/b-cm
m274     $  8.009370E-02
        1001.70c 4.150562818E-01
        5010.70c 1.295956850E-04
        5011.70c 5.249924969E-04
        8016.70c 2.205466403E-01
        12024.70c 1.319529236E-03
        12025.70c 1.670505584E-04
        12026.70c 1.839220443E-04
        13027.70c 3.545097091E-01
        14028.70c 1.264680988E-03
```

```
        14029.70c 6.403586011E-05
        14030.70c 4.250782915E-05
        22046.70c 5.247128245E-06
        22047.70c 4.731956743E-06
        22048.70c 4.688707408E-05
        22049.70c 3.440844219E-06
        22050.70c 3.294553091E-06
        24050.70c 6.623703154E-06
        24052.70c 1.275867883E-04
        24053.70c 1.446555431E-05
        24054.70c 3.593552828E-06
        25055.70c 8.118564497E-05
        26054.70c 2.970919712E-05
        26056.70c 4.659516603E-04
        26057.70c 1.076640019E-05
        26058.70c 1.421971729E-06
        29063.70c 2.368600300E-04
        29065.70c 1.055715780E-04
        92234.70c 5.043716532E-05
        92235.70c 4.700743308E-03
        92236.70c 2.017499098E-05
        92238.70c 2.723609424E-04
mt274     lwtr.60t
c       total atom density =  8.00993E-02 a/b-cm
m275     $  8.009930E-02
        1001.70c 4.150277825E-01
        5010.70c 7.715543681E-05
        5011.70c 3.125573663E-04
        8016.70c 2.230845805E-01
        12024.70c 1.319438632E-03
        12025.70c 1.670390881E-04
        12026.70c 1.839094155E-04
        13027.70c 3.513217906E-01
        14028.70c 1.257527914E-03
        14029.70c 6.367415630E-05
        14030.70c 4.226757974E-05
        22046.70c 5.246767957E-06
        22047.70c 4.731631829E-06
        22048.70c 4.688385463E-05
        22049.70c 3.440607957E-06
        22050.70c 3.294326875E-06
        24050.70c 6.623248346E-06
        24052.70c 1.275780277E-04
        24053.70c 1.446456105E-05
        24054.70c 3.593306081E-06
        25055.70c 8.078893055E-05
```

26054.70c 2.948206134E-05
26056.70c 4.623890450E-04
26057.70c 1.068408709E-05
26058.70c 1.411099954E-06
29063.70c 2.355403828E-04
29065.70c 1.049835494E-04
92234.70c 6.001132394E-05
92235.70c 5.593063481E-03
92236.70c 2.400472933E-05
92238.70c 3.240618484E-04
mt275 lwtr.60t
c total atom density = 8.00998E-02 a/b-cm
m276 $ 8.009980E-02
1001.70c 4.150249539E-01
5010.70c 7.238847983E-05
5011.70c 2.932455658E-04
8016.70c 2.233152705E-01
12024.70c 1.319429640E-03
12025.70c 1.670379497E-04
12026.70c 1.839081621E-04
13027.70c 3.510322544E-01
14028.70c 1.256882637E-03
14029.70c 6.364163735E-05
14030.70c 4.224606814E-05
22046.70c 5.246732199E-06
22047.70c 4.731599582E-06
22048.70c 4.688353511E-05
22049.70c 3.440584509E-06
22050.70c 3.294304423E-06
24050.70c 6.623203207E-06
24052.70c 1.275771582E-04
24053.70c 1.446446247E-05
24054.70c 3.593281592E-06
25055.70c 8.075279933E-05
26054.70c 2.946138595E-05
26056.70c 4.620650438E-04
26057.70c 1.067659853E-05
26058.70c 1.410116551E-06
29063.70c 2.354201754E-04
29065.70c 1.049300247E-04
92234.70c 6.088170406E-05
92235.70c 5.674174169E-03
92236.70c 2.435288137E-05
92238.70c 3.287612768E-04
mt276 lwtr.60t
c total atom density = 8.00968E-02 a/b-cm

```
m277     $  8.009680E-02
        1001.70c 4.150402676E-01
        5010.70c 9.981758763E-05
        5011.70c 4.043606908E-04
        8016.70c 2.219876270E-01
        12024.70c 1.319478324E-03
        12025.70c 1.670441131E-04
        12026.70c 1.839149480E-04
        13027.70c 3.526994551E-01
        14028.70c 1.260624542E-03
        14029.70c 6.383050991E-05
        14030.70c 4.237147708E-05
        22046.70c 5.246925794E-06
        22047.70c 4.731774170E-06
        22048.70c 4.688526503E-05
        22049.70c 3.440711460E-06
        22050.70c 3.294425978E-06
        24050.70c 6.623447592E-06
        24052.70c 1.275818656E-04
        24053.70c 1.446499618E-05
        24054.70c 3.593414178E-06
        25055.70c 8.096040635E-05
        26054.70c 2.958020555E-05
        26056.70c 4.639286088E-04
        26057.70c 1.071966584E-05
        26058.70c 1.415799268E-06
        29063.70c 2.361117856E-04
        29065.70c 1.052380285E-04
        92234.70c 5.587388807E-05
        92235.70c 5.207448565E-03
        92236.70c 2.234970505E-05
        92238.70c 3.017186460E-04
mt277     lwtr.60t
c       total atom density =  8.00933E-02 a/b-cm
m278     $  8.009330E-02
        1001.70c 4.150582303E-01
        5010.70c 1.330435213E-04
        5011.70c 5.389586693E-04
        8016.70c 2.203791224E-01
        12024.70c 1.319535430E-03
        12025.70c 1.670513426E-04
        12026.70c 1.839229077E-04
        13027.70c 3.547198801E-01
        14028.70c 1.265148886E-03
        14029.70c 6.406013276E-05
        14030.70c 4.252388520E-05
```

```
        22046.70c 5.247152878E-06
        22047.70c 4.731978958E-06
        22048.70c 4.688729419E-05
        22049.70c 3.440860372E-06
        22050.70c 3.294568558E-06
        24050.70c 6.623734250E-06
        24052.70c 1.275873873E-04
        24053.70c 1.446562222E-05
        24054.70c 3.593569698E-06
        25055.70c 8.121174609E-05
        26054.70c 2.972406940E-05
        26056.70c 4.661860768E-04
        26057.70c 1.077181947E-05
        26058.70c 1.422690075E-06
        29063.70c 2.369472914E-04
        29065.70c 1.056105288E-04
        92234.70c 4.980776173E-05
        92235.70c 4.642083843E-03
        92236.70c 1.992325452E-05
        92238.70c 2.689611892E-04
mt278     lwtr.60t
c
c          Inner fuel element--fueled Axial region 8
c       total atom density =  8.00804E-02 a/b-cm
m281     $  8.008040E-02
        1001.70c 4.151254862E-01
        5010.70c 2.548951954E-04
        5011.70c 1.032582720E-03
        8016.70c 2.144807936E-01
        12024.70c 1.319749248E-03
        12025.70c 1.670784116E-04
        12026.70c 1.839527105E-04
        13027.70c 3.621274753E-01
        14028.70c 1.281762407E-03
        14029.70c 6.490092886E-05
        14030.70c 4.308197206E-05
        22046.70c 5.248003125E-06
        22047.70c 4.732745727E-06
        22048.70c 4.689489180E-05
        22049.70c 3.441417928E-06
        22050.70c 3.295102409E-06
        24050.70c 6.624807558E-06
        24052.70c 1.276080615E-04
        24053.70c 1.446796622E-05
        24054.70c 3.594151999E-06
        25055.70c 8.213386753E-05
```

```
        26054.70c 3.025198541E-05
        26056.70c 4.744646272E-04
        26057.70c 1.096311202E-05
        26058.70c 1.447957956E-06
        29063.70c 2.400126456E-04
        29065.70c 1.069770364E-04
        92234.70c 2.756081382E-05
        92235.70c 2.568669646E-03
        92236.70c 1.102440045E-05
        92238.70c 1.488279950E-04
mt281     lwtr.60t
c       total atom density =  8.00839E-02 a/b-cm
m282     $  8.008390E-02
        1001.70c 4.151070034E-01
        5010.70c 2.216587037E-04
        5011.70c 8.979417024E-04
        8016.70c 2.160895464E-01
        12024.70c 1.319690488E-03
        12025.70c 1.670709727E-04
        12026.70c 1.839445203E-04
        13027.70c 3.601072047E-01
        14028.70c 1.277222542E-03
        14029.70c 6.467115227E-05
        14030.70c 4.292946189E-05
        22046.70c 5.247769466E-06
        22047.70c 4.732535008E-06
        22048.70c 4.689280387E-05
        22049.70c 3.441264704E-06
        22050.70c 3.294955700E-06
        24050.70c 6.624512599E-06
        24052.70c 1.276023799E-04
        24053.70c 1.446732206E-05
        24054.70c 3.593991975E-06
        25055.70c 8.188234568E-05
        26054.70c 3.010803809E-05
        26056.70c 4.722070986E-04
        26057.70c 1.091095311E-05
        26058.70c 1.441063153E-06
        29063.70c 2.391765753E-04
        29065.70c 1.066042844E-04
        92234.70c 3.362884434E-05
        92235.70c 3.134211839E-03
        92236.70c 1.345163763E-05
        92238.70c 1.815957345E-04
mt282     lwtr.60t
c       total atom density =  8.00880E-02 a/b-cm
```

```
m283     $  8.008800E-02
        1001.70c 4.150865749E-01
        5010.70c 1.834372651E-04
        5011.70c 7.431062827E-04
        8016.70c 2.179393685E-01
        12024.70c 1.319625542E-03
        12025.70c 1.670627507E-04
        12026.70c 1.839354679E-04
        13027.70c 3.577832660E-01
        14028.70c 1.272027823E-03
        14029.70c 6.440800517E-05
        14030.70c 4.275478875E-05
        22046.70c 5.247511209E-06
        22047.70c 4.732302107E-06
        22048.70c 4.689049615E-05
        22049.70c 3.441095350E-06
        22050.70c 3.294793546E-06
        24050.70c 6.624186589E-06
        24052.70c 1.275961003E-04
        24053.70c 1.446661008E-05
        24054.70c 3.593815105E-06
        25055.70c 8.159325414E-05
        26054.70c 2.994248660E-05
        26056.70c 4.696116853E-04
        26057.70c 1.085095647E-05
        26058.70c 1.433150848E-06
        29063.70c 2.382158471E-04
        29065.70c 1.061760028E-04
        92234.70c 4.060714769E-05
        92235.70c 3.784593057E-03
        92236.70c 1.624303388E-05
        92238.70c 2.192791469E-04
mt283     lwtr.60t
c       total atom density =  8.00937E-02 a/b-cm
m284     $  8.009370E-02
        1001.70c 4.150562818E-01
        5010.70c 1.295956850E-04
        5011.70c 5.249924969E-04
        8016.70c 2.205466403E-01
        12024.70c 1.319529236E-03
        12025.70c 1.670505584E-04
        12026.70c 1.839220443E-04
        13027.70c 3.545097091E-01
        14028.70c 1.264680988E-03
        14029.70c 6.403586011E-05
        14030.70c 4.250782915E-05
```

22046.70c 5.247128245E-06
22047.70c 4.731956743E-06
22048.70c 4.688707408E-05
22049.70c 3.440844219E-06
22050.70c 3.294553091E-06
24050.70c 6.623703154E-06
24052.70c 1.275867883E-04
24053.70c 1.446555431E-05
24054.70c 3.593552828E-06
25055.70c 8.118564497E-05
26054.70c 2.970919712E-05
26056.70c 4.659516603E-04
26057.70c 1.076640019E-05
26058.70c 1.421971729E-06
29063.70c 2.368600300E-04
29065.70c 1.055715780E-04
92234.70c 5.043716532E-05
92235.70c 4.700743308E-03
92236.70c 2.017499098E-05
92238.70c 2.723609424E-04
mt284 lwtr.60t
c total atom density = 8.00993E-02 a/b-cm
m285 $ 8.009930E-02
1001.70c 4.150277825E-01
5010.70c 7.715543681E-05
5011.70c 3.125573663E-04
8016.70c 2.230845805E-01
12024.70c 1.319438632E-03
12025.70c 1.670390881E-04
12026.70c 1.839094155E-04
13027.70c 3.513217906E-01
14028.70c 1.257527914E-03
14029.70c 6.367415630E-05
14030.70c 4.226757974E-05
22046.70c 5.246767957E-06
22047.70c 4.731631829E-06
22048.70c 4.688385463E-05
22049.70c 3.440607957E-06
22050.70c 3.294326875E-06
24050.70c 6.623248346E-06
24052.70c 1.275780277E-04
24053.70c 1.446456105E-05
24054.70c 3.593306081E-06
25055.70c 8.078893055E-05
26054.70c 2.948206134E-05
26056.70c 4.623890450E-04

26057.70c 1.068408709E-05
26058.70c 1.411099954E-06
29063.70c 2.355403828E-04
29065.70c 1.049835494E-04
92234.70c 6.001132394E-05
92235.70c 5.593063481E-03
92236.70c 2.400472933E-05
92238.70c 3.240618484E-04
mt285 lwtr.60t
c total atom density = 8.00998E-02 a/b-cm
m286 $ 8.009980E-02
1001.70c 4.150249539E-01
5010.70c 7.238847983E-05
5011.70c 2.932455658E-04
8016.70c 2.233152705E-01
12024.70c 1.319429640E-03
12025.70c 1.670379497E-04
12026.70c 1.839081621E-04
13027.70c 3.510322544E-01
14028.70c 1.256882637E-03
14029.70c 6.364163735E-05
14030.70c 4.224606814E-05
22046.70c 5.246732199E-06
22047.70c 4.731599582E-06
22048.70c 4.688353511E-05
22049.70c 3.440584509E-06
22050.70c 3.294304423E-06
24050.70c 6.623203207E-06
24052.70c 1.275771582E-04
24053.70c 1.446446247E-05
24054.70c 3.593281592E-06
25055.70c 8.075279933E-05
26054.70c 2.946138595E-05
26056.70c 4.620650438E-04
26057.70c 1.067659853E-05
26058.70c 1.410116551E-06
29063.70c 2.354201754E-04
29065.70c 1.049300247E-04
92234.70c 6.088170406E-05
92235.70c 5.674174169E-03
92236.70c 2.435288137E-05
92238.70c 3.287612768E-04
mt286 lwtr.60t
c total atom density = 8.00968E-02 a/b-cm
m287 $ 8.009680E-02
1001.70c 4.150402676E-01

```
        5010.70c 9.981758763E-05
        5011.70c 4.043606908E-04
        8016.70c 2.219876270E-01
        12024.70c 1.319478324E-03
        12025.70c 1.670441131E-04
        12026.70c 1.839149480E-04
        13027.70c 3.526994551E-01
        14028.70c 1.260624542E-03
        14029.70c 6.383050991E-05
        14030.70c 4.237147708E-05
        22046.70c 5.246925794E-06
        22047.70c 4.731774170E-06
        22048.70c 4.688526503E-05
        22049.70c 3.440711460E-06
        22050.70c 3.294425978E-06
        24050.70c 6.623447592E-06
        24052.70c 1.275818656E-04
        24053.70c 1.446499618E-05
        24054.70c 3.593414178E-06
        25055.70c 8.096040635E-05
        26054.70c 2.958020555E-05
        26056.70c 4.639286088E-04
        26057.70c 1.071966584E-05
        26058.70c 1.415799268E-06
        29063.70c 2.361117856E-04
        29065.70c 1.052380285E-04
        92234.70c 5.587388807E-05
        92235.70c 5.207448565E-03
        92236.70c 2.234970505E-05
        92238.70c 3.017186460E-04
mt287     lwtr.60t
c       total atom density =  8.00933E-02 a/b-cm
m288     $  8.009330E-02
        1001.70c 4.150582303E-01
        5010.70c 1.330435213E-04
        5011.70c 5.389586693E-04
        8016.70c 2.203791224E-01
        12024.70c 1.319535430E-03
        12025.70c 1.670513426E-04
        12026.70c 1.839229077E-04
        13027.70c 3.547198801E-01
        14028.70c 1.265148886E-03
        14029.70c 6.406013276E-05
        14030.70c 4.252388520E-05
        22046.70c 5.247152878E-06
        22047.70c 4.731978958E-06
```

```
        22048.70c 4.688729419E-05
        22049.70c 3.440860372E-06
        22050.70c 3.294568558E-06
        24050.70c 6.623734250E-06
        24052.70c 1.275873873E-04
        24053.70c 1.446562222E-05
        24054.70c 3.593569698E-06
        25055.70c 8.121174609E-05
        26054.70c 2.972406940E-05
        26056.70c 4.661860768E-04
        26057.70c 1.077181947E-05
        26058.70c 1.422690075E-06
        29063.70c 2.369472914E-04
        29065.70c 1.056105288E-04
        92234.70c 4.980776173E-05
        92235.70c 4.642083843E-03
        92236.70c 1.992325452E-05
        92238.70c 2.689611892E-04
mt288     lwtr.60t
c
c          Inner fuel element--fueled Axial region 9
c       total atom density =  8.00804E-02 a/b-cm
m291     $  8.008040E-02
        1001.70c 4.151254862E-01
        5010.70c 2.548951954E-04
        5011.70c 1.032582720E-03
        8016.70c 2.144807936E-01
        12024.70c 1.319749248E-03
        12025.70c 1.670784116E-04
        12026.70c 1.839527105E-04
        13027.70c 3.621274753E-01
        14028.70c 1.281762407E-03
        14029.70c 6.490092886E-05
        14030.70c 4.308197206E-05
        22046.70c 5.248003125E-06
        22047.70c 4.732745727E-06
        22048.70c 4.689489180E-05
        22049.70c 3.441417928E-06
        22050.70c 3.295102409E-06
        24050.70c 6.624807558E-06
        24052.70c 1.276080615E-04
        24053.70c 1.446796622E-05
        24054.70c 3.594151999E-06
        25055.70c 8.213386753E-05
        26054.70c 3.025198541E-05
        26056.70c 4.744646272E-04
```

```
        26057.70c 1.096311202E-05
        26058.70c 1.447957956E-06
        29063.70c 2.400126456E-04
        29065.70c 1.069770364E-04
        92234.70c 2.756081382E-05
        92235.70c 2.568669646E-03
        92236.70c 1.102440045E-05
        92238.70c 1.488279950E-04
mt291     lwtr.60t
c       total atom density =  8.00839E-02 a/b-cm
m292     $  8.008390E-02
        1001.70c 4.151070034E-01
        5010.70c 2.216587037E-04
        5011.70c 8.979417024E-04
        8016.70c 2.160895464E-01
        12024.70c 1.319690488E-03
        12025.70c 1.670709727E-04
        12026.70c 1.839445203E-04
        13027.70c 3.601072047E-01
        14028.70c 1.277222542E-03
        14029.70c 6.467115227E-05
        14030.70c 4.292946189E-05
        22046.70c 5.247769466E-06
        22047.70c 4.732535008E-06
        22048.70c 4.689280387E-05
        22049.70c 3.441264704E-06
        22050.70c 3.294955700E-06
        24050.70c 6.624512599E-06
        24052.70c 1.276023799E-04
        24053.70c 1.446732206E-05
        24054.70c 3.593991975E-06
        25055.70c 8.188234568E-05
        26054.70c 3.010803809E-05
        26056.70c 4.722070986E-04
        26057.70c 1.091095311E-05
        26058.70c 1.441063153E-06
        29063.70c 2.391765753E-04
        29065.70c 1.066042844E-04
        92234.70c 3.362884434E-05
        92235.70c 3.134211839E-03
        92236.70c 1.345163763E-05
        92238.70c 1.815957345E-04
mt292     lwtr.60t
c       total atom density =  8.00880E-02 a/b-cm
m293     $  8.008800E-02
        1001.70c 4.150865749E-01
```

```
        5010.70c 1.834372651E-04
        5011.70c 7.431062827E-04
        8016.70c 2.179393685E-01
        12024.70c 1.319625542E-03
        12025.70c 1.670627507E-04
        12026.70c 1.839354679E-04
        13027.70c 3.577832660E-01
        14028.70c 1.272027823E-03
        14029.70c 6.440800517E-05
        14030.70c 4.275478875E-05
        22046.70c 5.247511209E-06
        22047.70c 4.732302107E-06
        22048.70c 4.689049615E-05
        22049.70c 3.441095350E-06
        22050.70c 3.294793546E-06
        24050.70c 6.624186589E-06
        24052.70c 1.275961003E-04
        24053.70c 1.446661008E-05
        24054.70c 3.593815105E-06
        25055.70c 8.159325414E-05
        26054.70c 2.994248660E-05
        26056.70c 4.696116853E-04
        26057.70c 1.085095647E-05
        26058.70c 1.433150848E-06
        29063.70c 2.382158471E-04
        29065.70c 1.061760028E-04
        92234.70c 4.060714769E-05
        92235.70c 3.784593057E-03
        92236.70c 1.624303388E-05
        92238.70c 2.192791469E-04
mt293     lwtr.60t
c       total atom density =  8.00937E-02 a/b-cm
m294     $  8.009370E-02
        1001.70c 4.150562818E-01
        5010.70c 1.295956850E-04
        5011.70c 5.249924969E-04
        8016.70c 2.205466403E-01
        12024.70c 1.319529236E-03
        12025.70c 1.670505584E-04
        12026.70c 1.839220443E-04
        13027.70c 3.545097091E-01
        14028.70c 1.264680988E-03
        14029.70c 6.403586011E-05
        14030.70c 4.250782915E-05
        22046.70c 5.247128245E-06
        22047.70c 4.731956743E-06
```

```
        22048.70c 4.688707408E-05
        22049.70c 3.440844219E-06
        22050.70c 3.294553091E-06
        24050.70c 6.623703154E-06
        24052.70c 1.275867883E-04
        24053.70c 1.446555431E-05
        24054.70c 3.593552828E-06
        25055.70c 8.118564497E-05
        26054.70c 2.970919712E-05
        26056.70c 4.659516603E-04
        26057.70c 1.076640019E-05
        26058.70c 1.421971729E-06
        29063.70c 2.368600300E-04
        29065.70c 1.055715780E-04
        92234.70c 5.043716532E-05
        92235.70c 4.700743308E-03
        92236.70c 2.017499098E-05
        92238.70c 2.723609424E-04
mt294     lwtr.60t
c       total atom density =  8.00993E-02 a/b-cm
m295      $  8.009930E-02
        1001.70c 4.150277825E-01
        5010.70c 7.715543681E-05
        5011.70c 3.125573663E-04
        8016.70c 2.230845805E-01
        12024.70c 1.319438632E-03
        12025.70c 1.670390881E-04
        12026.70c 1.839094155E-04
        13027.70c 3.513217906E-01
        14028.70c 1.257527914E-03
        14029.70c 6.367415630E-05
        14030.70c 4.226757974E-05
        22046.70c 5.246767957E-06
        22047.70c 4.731631829E-06
        22048.70c 4.688385463E-05
        22049.70c 3.440607957E-06
        22050.70c 3.294326875E-06
        24050.70c 6.623248346E-06
        24052.70c 1.275780277E-04
        24053.70c 1.446456105E-05
        24054.70c 3.593306081E-06
        25055.70c 8.078893055E-05
        26054.70c 2.948206134E-05
        26056.70c 4.623890450E-04
        26057.70c 1.068408709E-05
        26058.70c 1.411099954E-06
```

```
        29063.70c 2.355403828E-04
        29065.70c 1.049835494E-04
        92234.70c 6.001132394E-05
        92235.70c 5.593063481E-03
        92236.70c 2.400472933E-05
        92238.70c 3.240618484E-04
mt295     lwtr.60t
c       total atom density =  8.00998E-02 a/b-cm
m296     $  8.009980E-02
        1001.70c 4.150249539E-01
        5010.70c 7.238847983E-05
        5011.70c 2.932455658E-04
        8016.70c 2.233152705E-01
        12024.70c 1.319429640E-03
        12025.70c 1.670379497E-04
        12026.70c 1.839081621E-04
        13027.70c 3.510322544E-01
        14028.70c 1.256882637E-03
        14029.70c 6.364163735E-05
        14030.70c 4.224606814E-05
        22046.70c 5.246732199E-06
        22047.70c 4.731599582E-06
        22048.70c 4.688353511E-05
        22049.70c 3.440584509E-06
        22050.70c 3.294304423E-06
        24050.70c 6.623203207E-06
        24052.70c 1.275771582E-04
        24053.70c 1.446446247E-05
        24054.70c 3.593281592E-06
        25055.70c 8.075279933E-05
        26054.70c 2.946138595E-05
        26056.70c 4.620650438E-04
        26057.70c 1.067659853E-05
        26058.70c 1.410116551E-06
        29063.70c 2.354201754E-04
        29065.70c 1.049300247E-04
        92234.70c 6.088170406E-05
        92235.70c 5.674174169E-03
        92236.70c 2.435288137E-05
        92238.70c 3.287612768E-04
mt296     lwtr.60t
c       total atom density =  8.00968E-02 a/b-cm
m297     $  8.009680E-02
        1001.70c 4.150402676E-01
        5010.70c 9.981758763E-05
        5011.70c 4.043606908E-04
```

```
        8016.70c 2.219876270E-01
        12024.70c 1.319478324E-03
        12025.70c 1.670441131E-04
        12026.70c 1.839149480E-04
        13027.70c 3.526994551E-01
        14028.70c 1.260624542E-03
        14029.70c 6.383050991E-05
        14030.70c 4.237147708E-05
        22046.70c 5.246925794E-06
        22047.70c 4.731774170E-06
        22048.70c 4.688526503E-05
        22049.70c 3.440711460E-06
        22050.70c 3.294425978E-06
        24050.70c 6.623447592E-06
        24052.70c 1.275818656E-04
        24053.70c 1.446499618E-05
        24054.70c 3.593414178E-06
        25055.70c 8.096040635E-05
        26054.70c 2.958020555E-05
        26056.70c 4.639286088E-04
        26057.70c 1.071966584E-05
        26058.70c 1.415799268E-06
        29063.70c 2.361117856E-04
        29065.70c 1.052380285E-04
        92234.70c 5.587388807E-05
        92235.70c 5.207448565E-03
        92236.70c 2.234970505E-05
        92238.70c 3.017186460E-04
mt297     lwtr.60t
c       total atom density =  8.00933E-02 a/b-cm
m298     $  8.009330E-02
        1001.70c 4.150582303E-01
        5010.70c 1.330435213E-04
        5011.70c 5.389586693E-04
        8016.70c 2.203791224E-01
        12024.70c 1.319535430E-03
        12025.70c 1.670513426E-04
        12026.70c 1.839229077E-04
        13027.70c 3.547198801E-01
        14028.70c 1.265148886E-03
        14029.70c 6.406013276E-05
        14030.70c 4.252388520E-05
        22046.70c 5.247152878E-06
        22047.70c 4.731978958E-06
        22048.70c 4.688729419E-05
        22049.70c 3.440860372E-06
```

```
        22050.70c 3.294568558E-06
        24050.70c 6.623734250E-06
        24052.70c 1.275873873E-04
        24053.70c 1.446562222E-05
        24054.70c 3.593569698E-06
        25055.70c 8.121174609E-05
        26054.70c 2.972406940E-05
        26056.70c 4.661860768E-04
        26057.70c 1.077181947E-05
        26058.70c 1.422690075E-06
        29063.70c 2.369472914E-04
        29065.70c 1.056105288E-04
        92234.70c 4.980776173E-05
        92235.70c 4.642083843E-03
        92236.70c 1.992325452E-05
        92238.70c 2.689611892E-04
mt298     lwtr.60t
c
c          Inner fuel element--fueled  central Axial region
c       total atom density =  8.00804E-02 a/b-cm
m201     $  8.008040E-02
        1001.70c 4.151254862E-01
        5010.70c 2.548951954E-04
        5011.70c 1.032582720E-03
        8016.70c 2.144807936E-01
        12024.70c 1.319749248E-03
        12025.70c 1.670784116E-04
        12026.70c 1.839527105E-04
        13027.70c 3.621274753E-01
        14028.70c 1.281762407E-03
        14029.70c 6.490092886E-05
        14030.70c 4.308197206E-05
        22046.70c 5.248003125E-06
        22047.70c 4.732745727E-06
        22048.70c 4.689489180E-05
        22049.70c 3.441417928E-06
        22050.70c 3.295102409E-06
        24050.70c 6.624807558E-06
        24052.70c 1.276080615E-04
        24053.70c 1.446796622E-05
        24054.70c 3.594151999E-06
        25055.70c 8.213386753E-05
        26054.70c 3.025198541E-05
        26056.70c 4.744646272E-04
        26057.70c 1.096311202E-05
        26058.70c 1.447957956E-06
```

```
        29063.70c 2.400126456E-04
        29065.70c 1.069770364E-04
        92234.70c 2.756081382E-05
        92235.70c 2.568669646E-03
        92236.70c 1.102440045E-05
        92238.70c 1.488279950E-04
mt201     lwtr.60t
c       total atom density =  8.00839E-02 a/b-cm
m202     $  8.008390E-02
        1001.70c 4.151070034E-01
        5010.70c 2.216587037E-04
        5011.70c 8.979417024E-04
        8016.70c 2.160895464E-01
        12024.70c 1.319690488E-03
        12025.70c 1.670709727E-04
        12026.70c 1.839445203E-04
        13027.70c 3.601072047E-01
        14028.70c 1.277222542E-03
        14029.70c 6.467115227E-05
        14030.70c 4.292946189E-05
        22046.70c 5.247769466E-06
        22047.70c 4.732535008E-06
        22048.70c 4.689280387E-05
        22049.70c 3.441264704E-06
        22050.70c 3.294955700E-06
        24050.70c 6.624512599E-06
        24052.70c 1.276023799E-04
        24053.70c 1.446732206E-05
        24054.70c 3.593991975E-06
        25055.70c 8.188234568E-05
        26054.70c 3.010803809E-05
        26056.70c 4.722070986E-04
        26057.70c 1.091095311E-05
        26058.70c 1.441063153E-06
        29063.70c 2.391765753E-04
        29065.70c 1.066042844E-04
        92234.70c 3.362884434E-05
        92235.70c 3.134211839E-03
        92236.70c 1.345163763E-05
        92238.70c 1.815957345E-04
mt202     lwtr.60t
c       total atom density =  8.00880E-02 a/b-cm
m203     $  8.008800E-02
        1001.70c 4.150865749E-01
        5010.70c 1.834372651E-04
        5011.70c 7.431062827E-04
```

```
      8016.70c 2.179393685E-01
      12024.70c 1.319625542E-03
      12025.70c 1.670627507E-04
      12026.70c 1.839354679E-04
      13027.70c 3.577832660E-01
      14028.70c 1.272027823E-03
      14029.70c 6.440800517E-05
      14030.70c 4.275478875E-05
      22046.70c 5.247511209E-06
      22047.70c 4.732302107E-06
      22048.70c 4.689049615E-05
      22049.70c 3.441095350E-06
      22050.70c 3.294793546E-06
      24050.70c 6.624186589E-06
      24052.70c 1.275961003E-04
      24053.70c 1.446661008E-05
      24054.70c 3.593815105E-06
      25055.70c 8.159325414E-05
      26054.70c 2.994248660E-05
      26056.70c 4.696116853E-04
      26057.70c 1.085095647E-05
      26058.70c 1.433150848E-06
      29063.70c 2.382158471E-04
      29065.70c 1.061760028E-04
      92234.70c 4.060714769E-05
      92235.70c 3.784593057E-03
      92236.70c 1.624303388E-05
      92238.70c 2.192791469E-04
mt203     lwtr.60t
c       total atom density =  8.00937E-02 a/b-cm
m204     $  8.009370E-02
      1001.70c 4.150562818E-01
      5010.70c 1.295956850E-04
      5011.70c 5.249924969E-04
      8016.70c 2.205466403E-01
      12024.70c 1.319529236E-03
      12025.70c 1.670505584E-04
      12026.70c 1.839220443E-04
      13027.70c 3.545097091E-01
      14028.70c 1.264680988E-03
      14029.70c 6.403586011E-05
      14030.70c 4.250782915E-05
      22046.70c 5.247128245E-06
      22047.70c 4.731956743E-06
      22048.70c 4.688707408E-05
      22049.70c 3.440844219E-06
```

```
        22050.70c 3.294553091E-06
        24050.70c 6.623703154E-06
        24052.70c 1.275867883E-04
        24053.70c 1.446555431E-05
        24054.70c 3.593552828E-06
        25055.70c 8.118564497E-05
        26054.70c 2.970919712E-05
        26056.70c 4.659516603E-04
        26057.70c 1.076640019E-05
        26058.70c 1.421971729E-06
        29063.70c 2.368600300E-04
        29065.70c 1.055715780E-04
        92234.70c 5.043716532E-05
        92235.70c 4.700743308E-03
        92236.70c 2.017499098E-05
        92238.70c 2.723609424E-04
mt204     lwtr.60t
c       total atom density =  8.00993E-02 a/b-cm
m205     $  8.009930E-02
        1001.70c 4.150277825E-01
        5010.70c 7.715543681E-05
        5011.70c 3.125573663E-04
        8016.70c 2.230845805E-01
        12024.70c 1.319438632E-03
        12025.70c 1.670390881E-04
        12026.70c 1.839094155E-04
        13027.70c 3.513217906E-01
        14028.70c 1.257527914E-03
        14029.70c 6.367415630E-05
        14030.70c 4.226757974E-05
        22046.70c 5.246767957E-06
        22047.70c 4.731631829E-06
        22048.70c 4.688385463E-05
        22049.70c 3.440607957E-06
        22050.70c 3.294326875E-06
        24050.70c 6.623248346E-06
        24052.70c 1.275780277E-04
        24053.70c 1.446456105E-05
        24054.70c 3.593306081E-06
        25055.70c 8.078893055E-05
        26054.70c 2.948206134E-05
        26056.70c 4.623890450E-04
        26057.70c 1.068408709E-05
        26058.70c 1.411099954E-06
        29063.70c 2.355403828E-04
        29065.70c 1.049835494E-04
```

```
        92234.70c 6.001132394E-05
        92235.70c 5.593063481E-03
        92236.70c 2.400472933E-05
        92238.70c 3.240618484E-04
mt205     lwtr.60t
c       total atom density =  8.00998E-02 a/b-cm
m206     $  8.009980E-02
        1001.70c 4.150249539E-01
        5010.70c 7.238847983E-05
        5011.70c 2.932455658E-04
        8016.70c 2.233152705E-01
        12024.70c 1.319429640E-03
        12025.70c 1.670379497E-04
        12026.70c 1.839081621E-04
        13027.70c 3.510322544E-01
        14028.70c 1.256882637E-03
        14029.70c 6.364163735E-05
        14030.70c 4.224606814E-05
        22046.70c 5.246732199E-06
        22047.70c 4.731599582E-06
        22048.70c 4.688353511E-05
        22049.70c 3.440584509E-06
        22050.70c 3.294304423E-06
        24050.70c 6.623203207E-06
        24052.70c 1.275771582E-04
        24053.70c 1.446446247E-05
        24054.70c 3.593281592E-06
        25055.70c 8.075279933E-05
        26054.70c 2.946138595E-05
        26056.70c 4.620650438E-04
        26057.70c 1.067659853E-05
        26058.70c 1.410116551E-06
        29063.70c 2.354201754E-04
        29065.70c 1.049300247E-04
        92234.70c 6.088170406E-05
        92235.70c 5.674174169E-03
        92236.70c 2.435288137E-05
        92238.70c 3.287612768E-04
mt206     lwtr.60t
c       total atom density =  8.00968E-02 a/b-cm
m207     $  8.009680E-02
        1001.70c 4.150402676E-01
        5010.70c 9.981758763E-05
        5011.70c 4.043606908E-04
        8016.70c 2.219876270E-01
        12024.70c 1.319478324E-03
```

```
        12025.70c 1.670441131E-04
        12026.70c 1.839149480E-04
        13027.70c 3.526994551E-01
        14028.70c 1.260624542E-03
        14029.70c 6.383050991E-05
        14030.70c 4.237147708E-05
        22046.70c 5.246925794E-06
        22047.70c 4.731774170E-06
        22048.70c 4.688526503E-05
        22049.70c 3.440711460E-06
        22050.70c 3.294425978E-06
        24050.70c 6.623447592E-06
        24052.70c 1.275818656E-04
        24053.70c 1.446499618E-05
        24054.70c 3.593414178E-06
        25055.70c 8.096040635E-05
        26054.70c 2.958020555E-05
        26056.70c 4.639286088E-04
        26057.70c 1.071966584E-05
        26058.70c 1.415799268E-06
        29063.70c 2.361117856E-04
        29065.70c 1.052380285E-04
        92234.70c 5.587388807E-05
        92235.70c 5.207448565E-03
        92236.70c 2.234970505E-05
        92238.70c 3.017186460E-04
mt207     lwtr.60t
c       total atom density =  8.00933E-02 a/b-cm
m208     $  8.009330E-02
        1001.70c 4.150582303E-01
        5010.70c 1.330435213E-04
        5011.70c 5.389586693E-04
        8016.70c 2.203791224E-01
        12024.70c 1.319535430E-03
        12025.70c 1.670513426E-04
        12026.70c 1.839229077E-04
        13027.70c 3.547198801E-01
        14028.70c 1.265148886E-03
        14029.70c 6.406013276E-05
        14030.70c 4.252388520E-05
        22046.70c 5.247152878E-06
        22047.70c 4.731978958E-06
        22048.70c 4.688729419E-05
        22049.70c 3.440860372E-06
        22050.70c 3.294568558E-06
        24050.70c 6.623734250E-06
```

```
      24052.70c 1.275873873E-04
      24053.70c 1.446562222E-05
      24054.70c 3.593569698E-06
      25055.70c 8.121174609E-05
      26054.70c 2.972406940E-05
      26056.70c 4.661860768E-04
      26057.70c 1.077181947E-05
      26058.70c 1.422690075E-06
      29063.70c 2.369472914E-04
      29065.70c 1.056105288E-04
      92234.70c 4.980776173E-05
      92235.70c 4.642083843E-03
      92236.70c 1.992325452E-05
      92238.70c 2.689611892E-04
mt208     lwtr.60t
c
c
c
c
c
c       Outer Fuel element Material Descriptions
c       ---------------------------------------
c
c       Aluminum Sidewalls
c
c         Outer fuel element--upper uncontrolled region
m72       1001.70c  3.35240E-02   8016.70c  1.66756E-02  13027.70c  2.92741E-02
        14028.70c  1.60187E-04  14029.70c  8.11095E-06  14030.70c  5.38414E-06
        22046.70c  1.05065E-06  22047.70c  9.47499E-07  22048.70c  9.38839E-06
        22049.70c  6.88974E-07  22050.70c  6.59683E-07  24050.70c  1.32629E-06
        24052.70c  2.55471E-05  24053.70c  2.89649E-06  24054.70c  7.19550E-07
        25055.70c  1.10987E-05  26054.70c  2.98072E-06  26056.70c  4.67489E-05
        26057.70c  1.08019E-06  26058.70c  1.42667E-07  29063.70c  3.02466E-05
        29065.70c  1.34813E-05  12024.70c  2.64216E-04  12025.70c  3.34493E-05
        12026.70c  3.68277E-05
mt72       lwtr.60t
c         Outer fuel element--lower uncontrolled region
m73       1001.70c  3.31702E-02   8016.70c  1.64987E-02  13027.70c  2.92741E-02
        14028.70c  1.60187E-04  14029.70c  8.11095E-06  14030.70c  5.38414E-06
        22046.70c  1.05065E-06  22047.70c  9.47499E-07  22048.70c  9.38839E-06
        22049.70c  6.88974E-07  22050.70c  6.59683E-07  24050.70c  1.32629E-06
        24052.70c  2.55471E-05  24053.70c  2.89649E-06  24054.70c  7.19550E-07
        25055.70c  1.10987E-05  26054.70c  2.98072E-06  26056.70c  4.67489E-05
        26057.70c  1.08019E-06  26058.70c  1.42667E-07  29063.70c  3.02466E-05
        29065.70c  1.34813E-05  12024.70c  2.64216E-04  12025.70c  3.34493E-05
        12026.70c  3.68277E-05
```

```
mt73      lwtr.60t
c
c      Outer Fuel Element  fueled region 1
c      total atom density =  8.00583E-02 a/b-cm
m311     $  8.005830E-02
        1001.70c 4.152398683E-01
        8016.70c 2.222692575E-01
        12024.70c 1.320112886E-03
        12025.70c 1.671244477E-04
        12026.70c 1.840033961E-04
        13027.70c 3.526529823E-01
        14028.70c 1.260743655E-03
        14029.70c 6.383672504E-05
        14030.70c 4.237561615E-05
        22046.70c 5.249449139E-06
        22047.70c 4.734049768E-06
        22048.70c 4.690781303E-05
        22049.70c 3.442366163E-06
        22050.70c 3.296010329E-06
        24050.70c 6.626632931E-06
        24052.70c 1.276432221E-04
        24053.70c 1.447195267E-05
        24054.70c 3.595142318E-06
        25055.70c 8.097248629E-05
        26054.70c 2.957894252E-05
        26056.70c 4.639093973E-04
        26057.70c 1.071922520E-05
        26058.70c 1.415743190E-06
        29063.70c 2.361354017E-04
        29065.70c 1.052485436E-04
        92234.70c 5.655740529E-05
        92235.70c 5.271158317E-03
        92236.70c 2.262313699E-05
        92238.70c 3.054099136E-04
mt311     lwtr.60t
c      total atom density =  8.00895E-02 a/b-cm
m312     $  8.008950E-02
        1001.70c 4.150781477E-01
        8016.70c 2.251593619E-01
        12024.70c 1.319598751E-03
        12025.70c 1.670593589E-04
        12026.70c 1.839317336E-04
        13027.70c 3.488285119E-01
        14028.70c 1.252024347E-03
        14029.70c 6.339557870E-05
        14030.70c 4.208267167E-05
```

```
        22046.70c 5.247404673E-06
        22047.70c 4.732206031E-06
        22048.70c 4.688954417E-05
        22049.70c 3.441025489E-06
        22050.70c 3.294726655E-06
        24050.70c 6.624052103E-06
        24052.70c 1.275935098E-04
        24053.70c 1.446631638E-05
        24054.70c 3.593742143E-06
        25055.70c 8.048521035E-05
        26054.70c 2.930521595E-05
        26056.70c 4.596158230E-04
        26057.70c 1.061999430E-05
        26058.70c 1.402643348E-06
        29063.70c 2.345251343E-04
        29065.70c 1.045308103E-04
        92234.70c 6.769514373E-05
        92235.70c 6.309191841E-03
        92236.70c 2.707820733E-05
        92238.70c 3.655535514E-04
mt312     lwtr.60t
c       total atom density =  8.01228E-02 a/b-cm
m313     $  8.012280E-02
        1001.70c 4.149055891E-01
        8016.70c 2.282371390E-01
        12024.70c 1.319050160E-03
        12025.70c 1.669899081E-04
        12026.70c 1.838552685E-04
        13027.70c 3.447557742E-01
        14028.70c 1.242747290E-03
        14029.70c 6.292565444E-05
        14030.70c 4.177075379E-05
        22046.70c 5.245223192E-06
        22047.70c 4.730238732E-06
        22048.70c 4.687005099E-05
        22049.70c 3.439594966E-06
        22050.70c 3.293356952E-06
        24050.70c 6.621298315E-06
        24052.70c 1.275404659E-04
        24053.70c 1.446030236E-05
        24054.70c 3.592248132E-06
        25055.70c 7.996612106E-05
        26054.70c 2.901346218E-05
        26056.70c 4.550402294E-04
        26057.70c 1.051427231E-05
        26058.70c 1.388680772E-06
```

29063.70c 2.328101191E-04
29065.70c 1.037663360E-04
92234.70c 7.955862160E-05
92235.70c 7.414867627E-03
92236.70c 3.182364833E-05
92238.70c 4.296167563E-04
mt313 lwtr.60t
c total atom density = 8.01530E-02 a/b-cm
m314 $ 8.015300E-02
1001.70c 4.147490712E-01
8016.70c 2.310280357E-01
12024.70c 1.318552565E-03
12025.70c 1.669269133E-04
12026.70c 1.837859114E-04
13027.70c 3.410625360E-01
14028.70c 1.234327441E-03
14029.70c 6.249931174E-05
14030.70c 4.148775754E-05
22046.70c 5.243244499E-06
22047.70c 4.728454310E-06
22048.70c 4.685236986E-05
22049.70c 3.438297423E-06
22050.70c 3.292114575E-06
24050.70c 6.618800514E-06
24052.70c 1.274923529E-04
24053.70c 1.445484740E-05
24054.70c 3.590893002E-06
25055.70c 7.949517309E-05
26054.70c 2.874900220E-05
26056.70c 4.508911802E-04
26057.70c 1.041841922E-05
26058.70c 1.376017632E-06
29063.70c 2.312538537E-04
29065.70c 1.030729430E-04
92234.70c 9.031796872E-05
92235.70c 8.417646762E-03
92236.70c 3.612751187E-05
92238.70c 4.877169812E-04
mt314 lwtr.60t
c total atom density = 8.01437E-02 a/b-cm
m315 $ 8.014370E-02
1001.70c 4.147973069E-01
8016.70c 2.301727393E-01
12024.70c 1.318705914E-03
12025.70c 1.669463270E-04
12026.70c 1.838072859E-04

```
        13027.70c 3.421939905E-01
        14028.70c 1.236910361E-03
        14029.70c 6.263010854E-05
        14030.70c 4.157456033E-05
        22046.70c 5.243854293E-06
        22047.70c 4.729004233E-06
        22048.70c 4.685781883E-05
        22049.70c 3.438697300E-06
        22050.70c 3.292497451E-06
        24050.70c 6.619570287E-06
        24052.70c 1.275071804E-04
        24053.70c 1.445652851E-05
        24054.70c 3.591310626E-06
        25055.70c 7.963955068E-05
        26054.70c 2.883008108E-05
        26056.70c 4.521626791E-04
        26057.70c 1.044780527E-05
        26058.70c 1.379895984E-06
        29063.70c 2.317299417E-04
        29065.70c 1.032853205E-04
        92234.70c 8.702166354E-05
        92235.70c 8.110429423E-03
        92236.70c 3.480896488E-05
        92238.70c 4.699170330E-04
mt315     lwtr.60t
c       total atom density =  8.00985E-02 a/b-cm
m316     $  8.009850E-02
        1001.70c 4.150316390E-01
        8016.70c 2.259880820E-01
        12024.70c 1.319450892E-03
        12025.70c 1.670406402E-04
        12026.70c 1.839111244E-04
        13027.70c 3.477319779E-01
        14028.70c 1.249524465E-03
        14029.70c 6.326887256E-05
        14030.70c 4.199867897E-05
        22046.70c 5.246816711E-06
        22047.70c 4.731675796E-06
        22048.70c 4.688429029E-05
        22049.70c 3.440639928E-06
        22050.70c 3.294357487E-06
        24050.70c 6.623309891E-06
        24052.70c 1.275792132E-04
        24053.70c 1.446469546E-05
        24054.70c 3.593339471E-06
        25055.70c 8.034547803E-05
```

```
        26054.70c 2.922665002E-05
        26056.70c 4.583832776E-04
        26057.70c 1.059152543E-05
        26058.70c 1.398878126E-06
        29063.70c 2.340631425E-04
        29065.70c 1.043252115E-04
        92234.70c 7.088911783E-05
        92235.70c 6.606867629E-03
        92236.70c 2.835584689E-05
        92238.70c 3.828013112E-04
mt316     lwtr.60t
c       total atom density =  8.00555E-02 a/b-cm
m317     $  8.005550E-02
        1001.70c 4.152545507E-01
        8016.70c 2.220098021E-01
        12024.70c 1.320159564E-03
        12025.70c 1.671303571E-04
        12026.70c 1.840099023E-04
        13027.70c 3.529964722E-01
        14028.70c 1.261537714E-03
        14029.70c 6.387695590E-05
        14030.70c 4.240222209E-05
        22046.70c 5.249634754E-06
        22047.70c 4.734217159E-06
        22048.70c 4.690947164E-05
        22049.70c 3.442487881E-06
        22050.70c 3.296126872E-06
        24050.70c 6.626867242E-06
        24052.70c 1.276477354E-04
        24053.70c 1.447246438E-05
        24054.70c 3.595269438E-06
        25055.70c 8.101644589E-05
        26054.70c 2.960359702E-05
        26056.70c 4.642967934E-04
        26057.70c 1.072816079E-05
        26058.70c 1.416929960E-06
        29063.70c 2.362799068E-04
        29065.70c 1.053132228E-04
        92234.70c 5.555422712E-05
        92235.70c 5.177659664E-03
        92236.70c 2.222184074E-05
        92238.70c 2.999932262E-04
mt317     lwtr.60t
c       total atom density =  8.00271E-02 a/b-cm
m318     $  8.002710E-02
        1001.70c 4.154017194E-01
```

```
      8016.70c 2.193781522E-01
      12024.70c 1.320627436E-03
      12025.70c 1.671895891E-04
      12026.70c 1.840751165E-04
      13027.70c 3.564791884E-01
      14028.70c 1.269457278E-03
      14029.70c 6.427834092E-05
      14030.70c 4.266866449E-05
      22046.70c 5.251495256E-06
      22047.70c 4.735894994E-06
      22048.70c 4.692609664E-05
      22049.70c 3.443707919E-06
      22050.70c 3.297295039E-06
      24050.70c 6.629215843E-06
      24052.70c 1.276929746E-04
      24053.70c 1.447759351E-05
      24054.70c 3.596543623E-06
      25055.70c 8.146026792E-05
      26054.70c 2.985300775E-05
      26056.70c 4.682075734E-04
      26057.70c 1.081853357E-05
      26058.70c 1.428865754E-06
      29063.70c 2.377469270E-04
      29065.70c 1.059668376E-04
      92234.70c 4.541111007E-05
      92235.70c 4.232315658E-03
      92236.70c 1.816459398E-05
      92238.70c 2.452193946E-04
mt318    lwtr.60t
c      total atom density =  8.00013E-02 a/b-cm
m319    $  8.000130E-02
      1001.70c 4.155354944E-01
      8016.70c 2.169850918E-01
      12024.70c 1.321052728E-03
      12025.70c 1.672434304E-04
      12026.70c 1.841343956E-04
      13027.70c 3.596464366E-01
      14028.70c 1.276678476E-03
      14029.70c 6.464391015E-05
      14030.70c 4.291140154E-05
      22046.70c 5.253186435E-06
      22047.70c 4.737420130E-06
      22048.70c 4.694120860E-05
      22049.70c 3.444816923E-06
      22050.70c 3.298356892E-06
      24050.70c 6.631350700E-06
```

```
        24052.70c 1.277340965E-04
        24053.70c 1.448225584E-05
        24054.70c 3.597701845E-06
        25055.70c 8.186386983E-05
        26054.70c 3.007986787E-05
        26056.70c 4.717645464E-04
        26057.70c 1.090072872E-05
        26058.70c 1.439713227E-06
        29063.70c 2.390809693E-04
        29065.70c 1.065613284E-04
        92234.70c 3.618501495E-05
        92235.70c 3.372443143E-03
        92236.70c 1.447413098E-05
        92238.70c 1.953992057E-04
mt319     lwtr.60t
c
c       Outer Fuel Element  fueled region 2
c       total atom density =  8.00583E-02 a/b-cm
m321     $  8.005830E-02
        1001.70c 4.152398683E-01
        8016.70c 2.222692575E-01
        12024.70c 1.320112886E-03
        12025.70c 1.671244477E-04
        12026.70c 1.840033961E-04
        13027.70c 3.526529823E-01
        14028.70c 1.260743655E-03
        14029.70c 6.383672504E-05
        14030.70c 4.237561615E-05
        22046.70c 5.249449139E-06
        22047.70c 4.734049768E-06
        22048.70c 4.690781303E-05
        22049.70c 3.442366163E-06
        22050.70c 3.296010329E-06
        24050.70c 6.626632931E-06
        24052.70c 1.276432221E-04
        24053.70c 1.447195267E-05
        24054.70c 3.595142318E-06
        25055.70c 8.097248629E-05
        26054.70c 2.957894252E-05
        26056.70c 4.639093973E-04
        26057.70c 1.071922520E-05
        26058.70c 1.415743190E-06
        29063.70c 2.361354017E-04
        29065.70c 1.052485436E-04
        92234.70c 5.655740529E-05
        92235.70c 5.271158317E-03
```

92236.70c 2.262313699E-05
92238.70c 3.054099136E-04
mt321 lwtr.60t
c total atom density = 8.00895E-02 a/b-cm
m322 $ 8.008950E-02
1001.70c 4.150781477E-01
8016.70c 2.251593619E-01
12024.70c 1.319598751E-03
12025.70c 1.670593589E-04
12026.70c 1.839317336E-04
13027.70c 3.488285119E-01
14028.70c 1.252024347E-03
14029.70c 6.339557870E-05
14030.70c 4.208267167E-05
22046.70c 5.247404673E-06
22047.70c 4.732206031E-06
22048.70c 4.688954417E-05
22049.70c 3.441025489E-06
22050.70c 3.294726655E-06
24050.70c 6.624052103E-06
24052.70c 1.275935098E-04
24053.70c 1.446631638E-05
24054.70c 3.593742143E-06
25055.70c 8.048521035E-05
26054.70c 2.930521595E-05
26056.70c 4.596158230E-04
26057.70c 1.061999430E-05
26058.70c 1.402643348E-06
29063.70c 2.345251343E-04
29065.70c 1.045308103E-04
92234.70c 6.769514373E-05
92235.70c 6.309191841E-03
92236.70c 2.707820733E-05
92238.70c 3.655535514E-04
mt322 lwtr.60t
c total atom density = 8.01228E-02 a/b-cm
m323 $ 8.012280E-02
1001.70c 4.149055891E-01
8016.70c 2.282371390E-01
12024.70c 1.319050160E-03
12025.70c 1.669899081E-04
12026.70c 1.838552685E-04
13027.70c 3.447557742E-01
14028.70c 1.242747290E-03
14029.70c 6.292565444E-05
14030.70c 4.177075379E-05

```
        22046.70c 5.245223192E-06
        22047.70c 4.730238732E-06
        22048.70c 4.687005099E-05
        22049.70c 3.439594966E-06
        22050.70c 3.293356952E-06
        24050.70c 6.621298315E-06
        24052.70c 1.275404659E-04
        24053.70c 1.446030236E-05
        24054.70c 3.592248132E-06
        25055.70c 7.996612106E-05
        26054.70c 2.901346218E-05
        26056.70c 4.550402294E-04
        26057.70c 1.051427231E-05
        26058.70c 1.388680772E-06
        29063.70c 2.328101191E-04
        29065.70c 1.037663360E-04
        92234.70c 7.955862160E-05
        92235.70c 7.414867627E-03
        92236.70c 3.182364833E-05
        92238.70c 4.296167563E-04
mt323     lwtr.60t
c       total atom density =  8.01530E-02 a/b-cm
m324     $  8.015300E-02
        1001.70c 4.147490712E-01
        8016.70c 2.310280357E-01
        12024.70c 1.318552565E-03
        12025.70c 1.669269133E-04
        12026.70c 1.837859114E-04
        13027.70c 3.410625360E-01
        14028.70c 1.234327441E-03
        14029.70c 6.249931174E-05
        14030.70c 4.148775754E-05
        22046.70c 5.243244499E-06
        22047.70c 4.728454310E-06
        22048.70c 4.685236986E-05
        22049.70c 3.438297423E-06
        22050.70c 3.292114575E-06
        24050.70c 6.618800514E-06
        24052.70c 1.274923529E-04
        24053.70c 1.445484740E-05
        24054.70c 3.590893002E-06
        25055.70c 7.949517309E-05
        26054.70c 2.874900220E-05
        26056.70c 4.508911802E-04
        26057.70c 1.041841922E-05
        26058.70c 1.376017632E-06
```

```
        29063.70c 2.312538537E-04
        29065.70c 1.030729430E-04
        92234.70c 9.031796872E-05
        92235.70c 8.417646762E-03
        92236.70c 3.612751187E-05
        92238.70c 4.877169812E-04
mt324     lwtr.60t
c       total atom density =  8.01437E-02 a/b-cm
m325     $  8.014370E-02
        1001.70c 4.147973069E-01
        8016.70c 2.301727393E-01
        12024.70c 1.318705914E-03
        12025.70c 1.669463270E-04
        12026.70c 1.838072859E-04
        13027.70c 3.421939905E-01
        14028.70c 1.236910361E-03
        14029.70c 6.263010854E-05
        14030.70c 4.157456033E-05
        22046.70c 5.243854293E-06
        22047.70c 4.729004233E-06
        22048.70c 4.685781883E-05
        22049.70c 3.438697300E-06
        22050.70c 3.292497451E-06
        24050.70c 6.619570287E-06
        24052.70c 1.275071804E-04
        24053.70c 1.445652851E-05
        24054.70c 3.591310626E-06
        25055.70c 7.963955068E-05
        26054.70c 2.883008108E-05
        26056.70c 4.521626791E-04
        26057.70c 1.044780527E-05
        26058.70c 1.379895984E-06
        29063.70c 2.317299417E-04
        29065.70c 1.032853205E-04
        92234.70c 8.702166354E-05
        92235.70c 8.110429423E-03
        92236.70c 3.480896488E-05
        92238.70c 4.699170330E-04
mt325     lwtr.60t
c       total atom density =  8.00985E-02 a/b-cm
m326     $  8.009850E-02
        1001.70c 4.150316390E-01
        8016.70c 2.259880820E-01
        12024.70c 1.319450892E-03
        12025.70c 1.670406402E-04
        12026.70c 1.839111244E-04
```

13027.70c 3.477319779E-01
14028.70c 1.249524465E-03
14029.70c 6.326887256E-05
14030.70c 4.199867897E-05
22046.70c 5.246816711E-06
22047.70c 4.731675796E-06
22048.70c 4.688429029E-05
22049.70c 3.440639928E-06
22050.70c 3.294357487E-06
24050.70c 6.623309891E-06
24052.70c 1.275792132E-04
24053.70c 1.446469546E-05
24054.70c 3.593339471E-06
25055.70c 8.034547803E-05
26054.70c 2.922665002E-05
26056.70c 4.583832776E-04
26057.70c 1.059152543E-05
26058.70c 1.398878126E-06
29063.70c 2.340631425E-04
29065.70c 1.043252115E-04
92234.70c 7.088911783E-05
92235.70c 6.606867629E-03
92236.70c 2.835584689E-05
92238.70c 3.828013112E-04
mt326 lwtr.60t
c total atom density = 8.00555E-02 a/b-cm
m327 $ 8.005550E-02
1001.70c 4.152545507E-01
8016.70c 2.220098021E-01
12024.70c 1.320159564E-03
12025.70c 1.671303571E-04
12026.70c 1.840099023E-04
13027.70c 3.529964722E-01
14028.70c 1.261537714E-03
14029.70c 6.387695590E-05
14030.70c 4.240222209E-05
22046.70c 5.249634754E-06
22047.70c 4.734217159E-06
22048.70c 4.690947164E-05
22049.70c 3.442487881E-06
22050.70c 3.296126872E-06
24050.70c 6.626867242E-06
24052.70c 1.276477354E-04
24053.70c 1.447246438E-05
24054.70c 3.595269438E-06
25055.70c 8.101644589E-05

```
        26054.70c 2.960359702E-05
        26056.70c 4.642967934E-04
        26057.70c 1.072816079E-05
        26058.70c 1.416929960E-06
        29063.70c 2.362799068E-04
        29065.70c 1.053132228E-04
        92234.70c 5.555422712E-05
        92235.70c 5.177659664E-03
        92236.70c 2.222184074E-05
        92238.70c 2.999932262E-04
mt327     lwtr.60t
c       total atom density =  8.00271E-02 a/b-cm
m328     $  8.002710E-02
        1001.70c 4.154017194E-01
        8016.70c 2.193781522E-01
        12024.70c 1.320627436E-03
        12025.70c 1.671895891E-04
        12026.70c 1.840751165E-04
        13027.70c 3.564791884E-01
        14028.70c 1.269457278E-03
        14029.70c 6.427834092E-05
        14030.70c 4.266866449E-05
        22046.70c 5.251495256E-06
        22047.70c 4.735894994E-06
        22048.70c 4.692609664E-05
        22049.70c 3.443707919E-06
        22050.70c 3.297295039E-06
        24050.70c 6.629215843E-06
        24052.70c 1.276929746E-04
        24053.70c 1.447759351E-05
        24054.70c 3.596543623E-06
        25055.70c 8.146026792E-05
        26054.70c 2.985300775E-05
        26056.70c 4.682075734E-04
        26057.70c 1.081853357E-05
        26058.70c 1.428865754E-06
        29063.70c 2.377469270E-04
        29065.70c 1.059668376E-04
        92234.70c 4.541111007E-05
        92235.70c 4.232315658E-03
        92236.70c 1.816459398E-05
        92238.70c 2.452193946E-04
mt328     lwtr.60t
c       total atom density =  8.00013E-02 a/b-cm
m329     $  8.000130E-02
        1001.70c 4.155354944E-01
```

```
        8016.70c 2.169850918E-01
        12024.70c 1.321052728E-03
        12025.70c 1.672434304E-04
        12026.70c 1.841343956E-04
        13027.70c 3.596464366E-01
        14028.70c 1.276678476E-03
        14029.70c 6.464391015E-05
        14030.70c 4.291140154E-05
        22046.70c 5.253186435E-06
        22047.70c 4.737420130E-06
        22048.70c 4.694120860E-05
        22049.70c 3.444816923E-06
        22050.70c 3.298356892E-06
        24050.70c 6.631350700E-06
        24052.70c 1.277340965E-04
        24053.70c 1.448225584E-05
        24054.70c 3.597701845E-06
        25055.70c 8.186386983E-05
        26054.70c 3.007986787E-05
        26056.70c 4.717645464E-04
        26057.70c 1.090072872E-05
        26058.70c 1.439713227E-06
        29063.70c 2.390809693E-04
        29065.70c 1.065613284E-04
        92234.70c 3.618501495E-05
        92235.70c 3.372443143E-03
        92236.70c 1.447413098E-05
        92238.70c 1.953992057E-04
mt329     lwtr.60t
c
c       Outer Fuel Element  fueled region 3
c       total atom density =  8.00583E-02 a/b-cm
m331     $  8.005830E-02
        1001.70c 4.152398683E-01
        8016.70c 2.222692575E-01
        12024.70c 1.320112886E-03
        12025.70c 1.671244477E-04
        12026.70c 1.840033961E-04
        13027.70c 3.526529823E-01
        14028.70c 1.260743655E-03
        14029.70c 6.383672504E-05
        14030.70c 4.237561615E-05
        22046.70c 5.249449139E-06
        22047.70c 4.734049768E-06
        22048.70c 4.690781303E-05
        22049.70c 3.442366163E-06
```

```
        22050.70c 3.296010329E-06
        24050.70c 6.626632931E-06
        24052.70c 1.276432221E-04
        24053.70c 1.447195267E-05
        24054.70c 3.595142318E-06
        25055.70c 8.097248629E-05
        26054.70c 2.957894252E-05
        26056.70c 4.639093973E-04
        26057.70c 1.071922520E-05
        26058.70c 1.415743190E-06
        29063.70c 2.361354017E-04
        29065.70c 1.052485436E-04
        92234.70c 5.655740529E-05
        92235.70c 5.271158317E-03
        92236.70c 2.262313699E-05
        92238.70c 3.054099136E-04
mt331     lwtr.60t
c       total atom density =  8.00895E-02 a/b-cm
m332     $  8.008950E-02
        1001.70c 4.150781477E-01
        8016.70c 2.251593619E-01
        12024.70c 1.319598751E-03
        12025.70c 1.670593589E-04
        12026.70c 1.839317336E-04
        13027.70c 3.488285119E-01
        14028.70c 1.252024347E-03
        14029.70c 6.339557870E-05
        14030.70c 4.208267167E-05
        22046.70c 5.247404673E-06
        22047.70c 4.732206031E-06
        22048.70c 4.688954417E-05
        22049.70c 3.441025489E-06
        22050.70c 3.294726655E-06
        24050.70c 6.624052103E-06
        24052.70c 1.275935098E-04
        24053.70c 1.446631638E-05
        24054.70c 3.593742143E-06
        25055.70c 8.048521035E-05
        26054.70c 2.930521595E-05
        26056.70c 4.596158230E-04
        26057.70c 1.061999430E-05
        26058.70c 1.402643348E-06
        29063.70c 2.345251343E-04
        29065.70c 1.045308103E-04
        92234.70c 6.769514373E-05
        92235.70c 6.309191841E-03
```

92236.70c 2.707820733E-05
92238.70c 3.655535514E-04
mt332 lwtr.60t
c total atom density = 8.01228E-02 a/b-cm
m333 $ 8.012280E-02
1001.70c 4.149055891E-01
8016.70c 2.282371390E-01
12024.70c 1.319050160E-03
12025.70c 1.669899081E-04
12026.70c 1.838552685E-04
13027.70c 3.447557742E-01
14028.70c 1.242747290E-03
14029.70c 6.292565444E-05
14030.70c 4.177075379E-05
22046.70c 5.245223192E-06
22047.70c 4.730238732E-06
22048.70c 4.687005099E-05
22049.70c 3.439594966E-06
22050.70c 3.293356952E-06
24050.70c 6.621298315E-06
24052.70c 1.275404659E-04
24053.70c 1.446030236E-05
24054.70c 3.592248132E-06
25055.70c 7.996612106E-05
26054.70c 2.901346218E-05
26056.70c 4.550402294E-04
26057.70c 1.051427231E-05
26058.70c 1.388680772E-06
29063.70c 2.328101191E-04
29065.70c 1.037663360E-04
92234.70c 7.955862160E-05
92235.70c 7.414867627E-03
92236.70c 3.182364833E-05
92238.70c 4.296167563E-04
mt333 lwtr.60t
c total atom density = 8.01530E-02 a/b-cm
m334 $ 8.015300E-02
1001.70c 4.147490712E-01
8016.70c 2.310280357E-01
12024.70c 1.318552565E-03
12025.70c 1.669269133E-04
12026.70c 1.837859114E-04
13027.70c 3.410625360E-01
14028.70c 1.234327441E-03
14029.70c 6.249931174E-05
14030.70c 4.148775754E-05

```
        22046.70c 5.243244499E-06
        22047.70c 4.728454310E-06
        22048.70c 4.685236986E-05
        22049.70c 3.438297423E-06
        22050.70c 3.292114575E-06
        24050.70c 6.618800514E-06
        24052.70c 1.274923529E-04
        24053.70c 1.445484740E-05
        24054.70c 3.590893002E-06
        25055.70c 7.949517309E-05
        26054.70c 2.874900220E-05
        26056.70c 4.508911802E-04
        26057.70c 1.041841922E-05
        26058.70c 1.376017632E-06
        29063.70c 2.312538537E-04
        29065.70c 1.030729430E-04
        92234.70c 9.031796872E-05
        92235.70c 8.417646762E-03
        92236.70c 3.612751187E-05
        92238.70c 4.877169812E-04
mt334    lwtr.60t
c        total atom density =  8.01437E-02 a/b-cm
m335     $  8.014370E-02
        1001.70c 4.147973069E-01
        8016.70c 2.301727393E-01
        12024.70c 1.318705914E-03
        12025.70c 1.669463270E-04
        12026.70c 1.838072859E-04
        13027.70c 3.421939905E-01
        14028.70c 1.236910361E-03
        14029.70c 6.263010854E-05
        14030.70c 4.157456033E-05
        22046.70c 5.243854293E-06
        22047.70c 4.729004233E-06
        22048.70c 4.685781883E-05
        22049.70c 3.438697300E-06
        22050.70c 3.292497451E-06
        24050.70c 6.619570287E-06
        24052.70c 1.275071804E-04
        24053.70c 1.445652851E-05
        24054.70c 3.591310626E-06
        25055.70c 7.963955068E-05
        26054.70c 2.883008108E-05
        26056.70c 4.521626791E-04
        26057.70c 1.044780527E-05
        26058.70c 1.379895984E-06
```

29063.70c 2.317299417E-04
29065.70c 1.032853205E-04
92234.70c 8.702166354E-05
92235.70c 8.110429423E-03
92236.70c 3.480896488E-05
92238.70c 4.699170330E-04
mt335 lwtr.60t
c total atom density = 8.00985E-02 a/b-cm
m336 $ 8.009850E-02
1001.70c 4.150316390E-01
8016.70c 2.259880820E-01
12024.70c 1.319450892E-03
12025.70c 1.670406402E-04
12026.70c 1.839111244E-04
13027.70c 3.477319779E-01
14028.70c 1.249524465E-03
14029.70c 6.326887256E-05
14030.70c 4.199867897E-05
22046.70c 5.246816711E-06
22047.70c 4.731675796E-06
22048.70c 4.688429029E-05
22049.70c 3.440639928E-06
22050.70c 3.294357487E-06
24050.70c 6.623309891E-06
24052.70c 1.275792132E-04
24053.70c 1.446469546E-05
24054.70c 3.593339471E-06
25055.70c 8.034547803E-05
26054.70c 2.922665002E-05
26056.70c 4.583832776E-04
26057.70c 1.059152543E-05
26058.70c 1.398878126E-06
29063.70c 2.340631425E-04
29065.70c 1.043252115E-04
92234.70c 7.088911783E-05
92235.70c 6.606867629E-03
92236.70c 2.835584689E-05
92238.70c 3.828013112E-04
mt336 lwtr.60t
c total atom density = 8.00555E-02 a/b-cm
m337 $ 8.005550E-02
1001.70c 4.152545507E-01
8016.70c 2.220098021E-01
12024.70c 1.320159564E-03
12025.70c 1.671303571E-04
12026.70c 1.840099023E-04

```
        13027.70c 3.529964722E-01
        14028.70c 1.261537714E-03
        14029.70c 6.387695590E-05
        14030.70c 4.240222209E-05
        22046.70c 5.249634754E-06
        22047.70c 4.734217159E-06
        22048.70c 4.690947164E-05
        22049.70c 3.442487881E-06
        22050.70c 3.296126872E-06
        24050.70c 6.626867242E-06
        24052.70c 1.276477354E-04
        24053.70c 1.447246438E-05
        24054.70c 3.595269438E-06
        25055.70c 8.101644589E-05
        26054.70c 2.960359702E-05
        26056.70c 4.642967934E-04
        26057.70c 1.072816079E-05
        26058.70c 1.416929960E-06
        29063.70c 2.362799068E-04
        29065.70c 1.053132228E-04
        92234.70c 5.555422712E-05
        92235.70c 5.177659664E-03
        92236.70c 2.222184074E-05
        92238.70c 2.999932262E-04
mt337     lwtr.60t
c       total atom density =  8.00271E-02 a/b-cm
m338     $  8.002710E-02
        1001.70c 4.154017194E-01
        8016.70c 2.193781522E-01
        12024.70c 1.320627436E-03
        12025.70c 1.671895891E-04
        12026.70c 1.840751165E-04
        13027.70c 3.564791884E-01
        14028.70c 1.269457278E-03
        14029.70c 6.427834092E-05
        14030.70c 4.266866449E-05
        22046.70c 5.251495256E-06
        22047.70c 4.735894994E-06
        22048.70c 4.692609664E-05
        22049.70c 3.443707919E-06
        22050.70c 3.297295039E-06
        24050.70c 6.629215843E-06
        24052.70c 1.276929746E-04
        24053.70c 1.447759351E-05
        24054.70c 3.596543623E-06
        25055.70c 8.146026792E-05
```

```
      26054.70c 2.985300775E-05
      26056.70c 4.682075734E-04
      26057.70c 1.081853357E-05
      26058.70c 1.428865754E-06
      29063.70c 2.377469270E-04
      29065.70c 1.059668376E-04
      92234.70c 4.541111007E-05
      92235.70c 4.232315658E-03
      92236.70c 1.816459398E-05
      92238.70c 2.452193946E-04
mt338    lwtr.60t
c      total atom density =  8.00013E-02 a/b-cm
m339    $  8.000130E-02
      1001.70c 4.155354944E-01
      8016.70c 2.169850918E-01
      12024.70c 1.321052728E-03
      12025.70c 1.672434304E-04
      12026.70c 1.841343956E-04
      13027.70c 3.596464366E-01
      14028.70c 1.276678476E-03
      14029.70c 6.464391015E-05
      14030.70c 4.291140154E-05
      22046.70c 5.253186435E-06
      22047.70c 4.737420130E-06
      22048.70c 4.694120860E-05
      22049.70c 3.444816923E-06
      22050.70c 3.298356892E-06
      24050.70c 6.631350700E-06
      24052.70c 1.277340965E-04
      24053.70c 1.448225584E-05
      24054.70c 3.597701845E-06
      25055.70c 8.186386983E-05
      26054.70c 3.007986787E-05
      26056.70c 4.717645464E-04
      26057.70c 1.090072872E-05
      26058.70c 1.439713227E-06
      29063.70c 2.390809693E-04
      29065.70c 1.065613284E-04
      92234.70c 3.618501495E-05
      92235.70c 3.372443143E-03
      92236.70c 1.447413098E-05
      92238.70c 1.953992057E-04
mt339    lwtr.60t
c
c      Outer Fuel Element  fueled region 4
c      total atom density =  8.00583E-02 a/b-cm
```

```
m341     $  8.005830E-02
        1001.70c 4.152398683E-01
        8016.70c 2.222692575E-01
        12024.70c 1.320112886E-03
        12025.70c 1.671244477E-04
        12026.70c 1.840033961E-04
        13027.70c 3.526529823E-01
        14028.70c 1.260743655E-03
        14029.70c 6.383672504E-05
        14030.70c 4.237561615E-05
        22046.70c 5.249449139E-06
        22047.70c 4.734049768E-06
        22048.70c 4.690781303E-05
        22049.70c 3.442366163E-06
        22050.70c 3.296010329E-06
        24050.70c 6.626632931E-06
        24052.70c 1.276432221E-04
        24053.70c 1.447195267E-05
        24054.70c 3.595142318E-06
        25055.70c 8.097248629E-05
        26054.70c 2.957894252E-05
        26056.70c 4.639093973E-04
        26057.70c 1.071922520E-05
        26058.70c 1.415743190E-06
        29063.70c 2.361354017E-04
        29065.70c 1.052485436E-04
        92234.70c 5.655740529E-05
        92235.70c 5.271158317E-03
        92236.70c 2.262313699E-05
        92238.70c 3.054099136E-04
mt341     lwtr.60t
c       total atom density =  8.00895E-02 a/b-cm
m342     $  8.008950E-02
        1001.70c 4.150781477E-01
        8016.70c 2.251593619E-01
        12024.70c 1.319598751E-03
        12025.70c 1.670593589E-04
        12026.70c 1.839317336E-04
        13027.70c 3.488285119E-01
        14028.70c 1.252024347E-03
        14029.70c 6.339557870E-05
        14030.70c 4.208267167E-05
        22046.70c 5.247404673E-06
        22047.70c 4.732206031E-06
        22048.70c 4.688954417E-05
        22049.70c 3.441025489E-06
```

```
        22050.70c 3.294726655E-06
        24050.70c 6.624052103E-06
        24052.70c 1.275935098E-04
        24053.70c 1.446631638E-05
        24054.70c 3.593742143E-06
        25055.70c 8.048521035E-05
        26054.70c 2.930521595E-05
        26056.70c 4.596158230E-04
        26057.70c 1.061999430E-05
        26058.70c 1.402643348E-06
        29063.70c 2.345251343E-04
        29065.70c 1.045308103E-04
        92234.70c 6.769514373E-05
        92235.70c 6.309191841E-03
        92236.70c 2.707820733E-05
        92238.70c 3.655535514E-04
mt342     lwtr.60t
c       total atom density =  8.01228E-02 a/b-cm
m343     $  8.012280E-02
        1001.70c 4.149055891E-01
        8016.70c 2.282371390E-01
        12024.70c 1.319050160E-03
        12025.70c 1.669899081E-04
        12026.70c 1.838552685E-04
        13027.70c 3.447557742E-01
        14028.70c 1.242747290E-03
        14029.70c 6.292565444E-05
        14030.70c 4.177075379E-05
        22046.70c 5.245223192E-06
        22047.70c 4.730238732E-06
        22048.70c 4.687005099E-05
        22049.70c 3.439594966E-06
        22050.70c 3.293356952E-06
        24050.70c 6.621298315E-06
        24052.70c 1.275404659E-04
        24053.70c 1.446030236E-05
        24054.70c 3.592248132E-06
        25055.70c 7.996612106E-05
        26054.70c 2.901346218E-05
        26056.70c 4.550402294E-04
        26057.70c 1.051427231E-05
        26058.70c 1.388680772E-06
        29063.70c 2.328101191E-04
        29065.70c 1.037663360E-04
        92234.70c 7.955862160E-05
        92235.70c 7.414867627E-03
```

92236.70c 3.182364833E-05
92238.70c 4.296167563E-04
mt343 lwtr.60t
c total atom density = 8.01530E-02 a/b-cm
m344 $ 8.015300E-02
1001.70c 4.147490712E-01
8016.70c 2.310280357E-01
12024.70c 1.318552565E-03
12025.70c 1.669269133E-04
12026.70c 1.837859114E-04
13027.70c 3.410625360E-01
14028.70c 1.234327441E-03
14029.70c 6.249931174E-05
14030.70c 4.148775754E-05
22046.70c 5.243244499E-06
22047.70c 4.728454310E-06
22048.70c 4.685236986E-05
22049.70c 3.438297423E-06
22050.70c 3.292114575E-06
24050.70c 6.618800514E-06
24052.70c 1.274923529E-04
24053.70c 1.445484740E-05
24054.70c 3.590893002E-06
25055.70c 7.949517309E-05
26054.70c 2.874900220E-05
26056.70c 4.508911802E-04
26057.70c 1.041841922E-05
26058.70c 1.376017632E-06
29063.70c 2.312538537E-04
29065.70c 1.030729430E-04
92234.70c 9.031796872E-05
92235.70c 8.417646762E-03
92236.70c 3.612751187E-05
92238.70c 4.877169812E-04
mt344 lwtr.60t
c total atom density = 8.01437E-02 a/b-cm
m345 $ 8.014370E-02
1001.70c 4.147973069E-01
8016.70c 2.301727393E-01
12024.70c 1.318705914E-03
12025.70c 1.669463270E-04
12026.70c 1.838072859E-04
13027.70c 3.421939905E-01
14028.70c 1.236910361E-03
14029.70c 6.263010854E-05
14030.70c 4.157456033E-05

22046.70c 5.243854293E-06
22047.70c 4.729004233E-06
22048.70c 4.685781883E-05
22049.70c 3.438697300E-06
22050.70c 3.292497451E-06
24050.70c 6.619570287E-06
24052.70c 1.275071804E-04
24053.70c 1.445652851E-05
24054.70c 3.591310626E-06
25055.70c 7.963955068E-05
26054.70c 2.883008108E-05
26056.70c 4.521626791E-04
26057.70c 1.044780527E-05
26058.70c 1.379895984E-06
29063.70c 2.317299417E-04
29065.70c 1.032853205E-04
92234.70c 8.702166354E-05
92235.70c 8.110429423E-03
92236.70c 3.480896488E-05
92238.70c 4.699170330E-04
mt345 lwtr.60t
c total atom density = 8.00985E-02 a/b-cm
m346 $ 8.009850E-02
1001.70c 4.150316390E-01
8016.70c 2.259880820E-01
12024.70c 1.319450892E-03
12025.70c 1.670406402E-04
12026.70c 1.839111244E-04
13027.70c 3.477319779E-01
14028.70c 1.249524465E-03
14029.70c 6.326887256E-05
14030.70c 4.199867897E-05
22046.70c 5.246816711E-06
22047.70c 4.731675796E-06
22048.70c 4.688429029E-05
22049.70c 3.440639928E-06
22050.70c 3.294357487E-06
24050.70c 6.623309891E-06
24052.70c 1.275792132E-04
24053.70c 1.446469546E-05
24054.70c 3.593339471E-06
25055.70c 8.034547803E-05
26054.70c 2.922665002E-05
26056.70c 4.583832776E-04
26057.70c 1.059152543E-05
26058.70c 1.398878126E-06

29063.70c 2.340631425E-04
29065.70c 1.043252115E-04
92234.70c 7.088911783E-05
92235.70c 6.606867629E-03
92236.70c 2.835584689E-05
92238.70c 3.828013112E-04
mt346 lwtr.60t
c total atom density = 8.00555E-02 a/b-cm
m347 $ 8.005550E-02
1001.70c 4.152545507E-01
8016.70c 2.220098021E-01
12024.70c 1.320159564E-03
12025.70c 1.671303571E-04
12026.70c 1.840099023E-04
13027.70c 3.529964722E-01
14028.70c 1.261537714E-03
14029.70c 6.387695590E-05
14030.70c 4.240222209E-05
22046.70c 5.249634754E-06
22047.70c 4.734217159E-06
22048.70c 4.690947164E-05
22049.70c 3.442487881E-06
22050.70c 3.296126872E-06
24050.70c 6.626867242E-06
24052.70c 1.276477354E-04
24053.70c 1.447246438E-05
24054.70c 3.595269438E-06
25055.70c 8.101644589E-05
26054.70c 2.960359702E-05
26056.70c 4.642967934E-04
26057.70c 1.072816079E-05
26058.70c 1.416929960E-06
29063.70c 2.362799068E-04
29065.70c 1.053132228E-04
92234.70c 5.555422712E-05
92235.70c 5.177659664E-03
92236.70c 2.222184074E-05
92238.70c 2.999932262E-04
mt347 lwtr.60t
c total atom density = 8.00271E-02 a/b-cm
m348 $ 8.002710E-02
1001.70c 4.154017194E-01
8016.70c 2.193781522E-01
12024.70c 1.320627436E-03
12025.70c 1.671895891E-04
12026.70c 1.840751165E-04

```
        13027.70c 3.564791884E-01
        14028.70c 1.269457278E-03
        14029.70c 6.427834092E-05
        14030.70c 4.266866449E-05
        22046.70c 5.251495256E-06
        22047.70c 4.735894994E-06
        22048.70c 4.692609664E-05
        22049.70c 3.443707919E-06
        22050.70c 3.297295039E-06
        24050.70c 6.629215843E-06
        24052.70c 1.276929746E-04
        24053.70c 1.447759351E-05
        24054.70c 3.596543623E-06
        25055.70c 8.146026792E-05
        26054.70c 2.985300775E-05
        26056.70c 4.682075734E-04
        26057.70c 1.081853357E-05
        26058.70c 1.428865754E-06
        29063.70c 2.377469270E-04
        29065.70c 1.059668376E-04
        92234.70c 4.541111007E-05
        92235.70c 4.232315658E-03
        92236.70c 1.816459398E-05
        92238.70c 2.452193946E-04
mt348     lwtr.60t
c       total atom density =  8.00013E-02 a/b-cm
m349     $  8.000130E-02
        1001.70c 4.155354944E-01
        8016.70c 2.169850918E-01
        12024.70c 1.321052728E-03
        12025.70c 1.672434304E-04
        12026.70c 1.841343956E-04
        13027.70c 3.596464366E-01
        14028.70c 1.276678476E-03
        14029.70c 6.464391015E-05
        14030.70c 4.291140154E-05
        22046.70c 5.253186435E-06
        22047.70c 4.737420130E-06
        22048.70c 4.694120860E-05
        22049.70c 3.444816923E-06
        22050.70c 3.298356892E-06
        24050.70c 6.631350700E-06
        24052.70c 1.277340965E-04
        24053.70c 1.448225584E-05
        24054.70c 3.597701845E-06
        25055.70c 8.186386983E-05
```

```
        26054.70c 3.007986787E-05
        26056.70c 4.717645464E-04
        26057.70c 1.090072872E-05
        26058.70c 1.439713227E-06
        29063.70c 2.390809693E-04
        29065.70c 1.065613284E-04
        92234.70c 3.618501495E-05
        92235.70c 3.372443143E-03
        92236.70c 1.447413098E-05
        92238.70c 1.953992057E-04
mt349     lwtr.60t
c
c       Outer Fuel Element  fueled region
c       total atom density =  8.00583E-02 a/b-cm
m351     $  8.005830E-02
        1001.70c 4.152398683E-01
        8016.70c 2.222692575E-01
        12024.70c 1.320112886E-03
        12025.70c 1.671244477E-04
        12026.70c 1.840033961E-04
        13027.70c 3.526529823E-01
        14028.70c 1.260743655E-03
        14029.70c 6.383672504E-05
        14030.70c 4.237561615E-05
        22046.70c 5.249449139E-06
        22047.70c 4.734049768E-06
        22048.70c 4.690781303E-05
        22049.70c 3.442366163E-06
        22050.70c 3.296010329E-06
        24050.70c 6.626632931E-06
        24052.70c 1.276432221E-04
        24053.70c 1.447195267E-05
        24054.70c 3.595142318E-06
        25055.70c 8.097248629E-05
        26054.70c 2.957894252E-05
        26056.70c 4.639093973E-04
        26057.70c 1.071922520E-05
        26058.70c 1.415743190E-06
        29063.70c 2.361354017E-04
        29065.70c 1.052485436E-04
        92234.70c 5.655740529E-05
        92235.70c 5.271158317E-03
        92236.70c 2.262313699E-05
        92238.70c 3.054099136E-04
mt351     lwtr.60t
c       total atom density =  8.00895E-02 a/b-cm
```

```
m352     $  8.008950E-02
        1001.70c 4.150781477E-01
        8016.70c 2.251593619E-01
        12024.70c 1.319598751E-03
        12025.70c 1.670593589E-04
        12026.70c 1.839317336E-04
        13027.70c 3.488285119E-01
        14028.70c 1.252024347E-03
        14029.70c 6.339557870E-05
        14030.70c 4.208267167E-05
        22046.70c 5.247404673E-06
        22047.70c 4.732206031E-06
        22048.70c 4.688954417E-05
        22049.70c 3.441025489E-06
        22050.70c 3.294726655E-06
        24050.70c 6.624052103E-06
        24052.70c 1.275935098E-04
        24053.70c 1.446631638E-05
        24054.70c 3.593742143E-06
        25055.70c 8.048521035E-05
        26054.70c 2.930521595E-05
        26056.70c 4.596158230E-04
        26057.70c 1.061999430E-05
        26058.70c 1.402643348E-06
        29063.70c 2.345251343E-04
        29065.70c 1.045308103E-04
        92234.70c 6.769514373E-05
        92235.70c 6.309191841E-03
        92236.70c 2.707820733E-05
        92238.70c 3.655535514E-04
mt352     lwtr.60t
c       total atom density =  8.01228E-02 a/b-cm
m353     $  8.012280E-02
        1001.70c 4.149055891E-01
        8016.70c 2.282371390E-01
        12024.70c 1.319050160E-03
        12025.70c 1.669899081E-04
        12026.70c 1.838552685E-04
        13027.70c 3.447557742E-01
        14028.70c 1.242747290E-03
        14029.70c 6.292565444E-05
        14030.70c 4.177075379E-05
        22046.70c 5.245223192E-06
        22047.70c 4.730238732E-06
        22048.70c 4.687005099E-05
        22049.70c 3.439594966E-06
```

```
        22050.70c 3.293356952E-06
        24050.70c 6.621298315E-06
        24052.70c 1.275404659E-04
        24053.70c 1.446030236E-05
        24054.70c 3.592248132E-06
        25055.70c 7.996612106E-05
        26054.70c 2.901346218E-05
        26056.70c 4.550402294E-04
        26057.70c 1.051427231E-05
        26058.70c 1.388680772E-06
        29063.70c 2.328101191E-04
        29065.70c 1.037663360E-04
        92234.70c 7.955862160E-05
        92235.70c 7.414867627E-03
        92236.70c 3.182364833E-05
        92238.70c 4.296167563E-04
mt353     lwtr.60t
c       total atom density =  8.01530E-02 a/b-cm
m354     $  8.015300E-02
        1001.70c 4.147490712E-01
        8016.70c 2.310280357E-01
        12024.70c 1.318552565E-03
        12025.70c 1.669269133E-04
        12026.70c 1.837859114E-04
        13027.70c 3.410625360E-01
        14028.70c 1.234327441E-03
        14029.70c 6.249931174E-05
        14030.70c 4.148775754E-05
        22046.70c 5.243244499E-06
        22047.70c 4.728454310E-06
        22048.70c 4.685236986E-05
        22049.70c 3.438297423E-06
        22050.70c 3.292114575E-06
        24050.70c 6.618800514E-06
        24052.70c 1.274923529E-04
        24053.70c 1.445484740E-05
        24054.70c 3.590893002E-06
        25055.70c 7.949517309E-05
        26054.70c 2.874900220E-05
        26056.70c 4.508911802E-04
        26057.70c 1.041841922E-05
        26058.70c 1.376017632E-06
        29063.70c 2.312538537E-04
        29065.70c 1.030729430E-04
        92234.70c 9.031796872E-05
        92235.70c 8.417646762E-03
```

```
        92236.70c 3.612751187E-05
        92238.70c 4.877169812E-04
mt354     lwtr.60t
c       total atom density =  8.01437E-02 a/b-cm
m355     $  8.014370E-02
        1001.70c 4.147973069E-01
        8016.70c 2.301727393E-01
        12024.70c 1.318705914E-03
        12025.70c 1.669463270E-04
        12026.70c 1.838072859E-04
        13027.70c 3.421939905E-01
        14028.70c 1.236910361E-03
        14029.70c 6.263010854E-05
        14030.70c 4.157456033E-05
        22046.70c 5.243854293E-06
        22047.70c 4.729004233E-06
        22048.70c 4.685781883E-05
        22049.70c 3.438697300E-06
        22050.70c 3.292497451E-06
        24050.70c 6.619570287E-06
        24052.70c 1.275071804E-04
        24053.70c 1.445652851E-05
        24054.70c 3.591310626E-06
        25055.70c 7.963955068E-05
        26054.70c 2.883008108E-05
        26056.70c 4.521626791E-04
        26057.70c 1.044780527E-05
        26058.70c 1.379895984E-06
        29063.70c 2.317299417E-04
        29065.70c 1.032853205E-04
        92234.70c 8.702166354E-05
        92235.70c 8.110429423E-03
        92236.70c 3.480896488E-05
        92238.70c 4.699170330E-04
mt355     lwtr.60t
c       total atom density =  8.00985E-02 a/b-cm
m356     $  8.009850E-02
        1001.70c 4.150316390E-01
        8016.70c 2.259880820E-01
        12024.70c 1.319450892E-03
        12025.70c 1.670406402E-04
        12026.70c 1.839111244E-04
        13027.70c 3.477319779E-01
        14028.70c 1.249524465E-03
        14029.70c 6.326887256E-05
        14030.70c 4.199867897E-05
```

```
        22046.70c 5.246816711E-06
        22047.70c 4.731675796E-06
        22048.70c 4.688429029E-05
        22049.70c 3.440639928E-06
        22050.70c 3.294357487E-06
        24050.70c 6.623309891E-06
        24052.70c 1.275792132E-04
        24053.70c 1.446469546E-05
        24054.70c 3.593339471E-06
        25055.70c 8.034547803E-05
        26054.70c 2.922665002E-05
        26056.70c 4.583832776E-04
        26057.70c 1.059152543E-05
        26058.70c 1.398878126E-06
        29063.70c 2.340631425E-04
        29065.70c 1.043252115E-04
        92234.70c 7.088911783E-05
        92235.70c 6.606867629E-03
        92236.70c 2.835584689E-05
        92238.70c 3.828013112E-04
mt356     lwtr.60t
c       total atom density =  8.00555E-02 a/b-cm
m357     $  8.005550E-02
        1001.70c 4.152545507E-01
        8016.70c 2.220098021E-01
        12024.70c 1.320159564E-03
        12025.70c 1.671303571E-04
        12026.70c 1.840099023E-04
        13027.70c 3.529964722E-01
        14028.70c 1.261537714E-03
        14029.70c 6.387695590E-05
        14030.70c 4.240222209E-05
        22046.70c 5.249634754E-06
        22047.70c 4.734217159E-06
        22048.70c 4.690947164E-05
        22049.70c 3.442487881E-06
        22050.70c 3.296126872E-06
        24050.70c 6.626867242E-06
        24052.70c 1.276477354E-04
        24053.70c 1.447246438E-05
        24054.70c 3.595269438E-06
        25055.70c 8.101644589E-05
        26054.70c 2.960359702E-05
        26056.70c 4.642967934E-04
        26057.70c 1.072816079E-05
        26058.70c 1.416929960E-06
```

```
        29063.70c 2.362799068E-04
        29065.70c 1.053132228E-04
        92234.70c 5.555422712E-05
        92235.70c 5.177659664E-03
        92236.70c 2.222184074E-05
        92238.70c 2.999932262E-04
mt357     lwtr.60t
c       total atom density =  8.00271E-02 a/b-cm
m358     $  8.002710E-02
        1001.70c 4.154017194E-01
        8016.70c 2.193781522E-01
        12024.70c 1.320627436E-03
        12025.70c 1.671895891E-04
        12026.70c 1.840751165E-04
        13027.70c 3.564791884E-01
        14028.70c 1.269457278E-03
        14029.70c 6.427834092E-05
        14030.70c 4.266866449E-05
        22046.70c 5.251495256E-06
        22047.70c 4.735894994E-06
        22048.70c 4.692609664E-05
        22049.70c 3.443707919E-06
        22050.70c 3.297295039E-06
        24050.70c 6.629215843E-06
        24052.70c 1.276929746E-04
        24053.70c 1.447759351E-05
        24054.70c 3.596543623E-06
        25055.70c 8.146026792E-05
        26054.70c 2.985300775E-05
        26056.70c 4.682075734E-04
        26057.70c 1.081853357E-05
        26058.70c 1.428865754E-06
        29063.70c 2.377469270E-04
        29065.70c 1.059668376E-04
        92234.70c 4.541111007E-05
        92235.70c 4.232315658E-03
        92236.70c 1.816459398E-05
        92238.70c 2.452193946E-04
mt358     lwtr.60t
c       total atom density =  8.00013E-02 a/b-cm
m359     $  8.000130E-02
        1001.70c 4.155354944E-01
        8016.70c 2.169850918E-01
        12024.70c 1.321052728E-03
        12025.70c 1.672434304E-04
        12026.70c 1.841343956E-04
```

```
        13027.70c 3.596464366E-01
        14028.70c 1.276678476E-03
        14029.70c 6.464391015E-05
        14030.70c 4.291140154E-05
        22046.70c 5.253186435E-06
        22047.70c 4.737420130E-06
        22048.70c 4.694120860E-05
        22049.70c 3.444816923E-06
        22050.70c 3.298356892E-06
        24050.70c 6.631350700E-06
        24052.70c 1.277340965E-04
        24053.70c 1.448225584E-05
        24054.70c 3.597701845E-06
        25055.70c 8.186386983E-05
        26054.70c 3.007986787E-05
        26056.70c 4.717645464E-04
        26057.70c 1.090072872E-05
        26058.70c 1.439713227E-06
        29063.70c 2.390809693E-04
        29065.70c 1.065613284E-04
        92234.70c 3.618501495E-05
        92235.70c 3.372443143E-03
        92236.70c 1.447413098E-05
        92238.70c 1.953992057E-04
mt359     lwtr.60t
c
c       Outer Fuel Element  fueled region 6
c       total atom density =  8.00583E-02 a/b-cm
m361     $  8.005830E-02
        1001.70c 4.152398683E-01
        8016.70c 2.222692575E-01
        12024.70c 1.320112886E-03
        12025.70c 1.671244477E-04
        12026.70c 1.840033961E-04
        13027.70c 3.526529823E-01
        14028.70c 1.260743655E-03
        14029.70c 6.383672504E-05
        14030.70c 4.237561615E-05
        22046.70c 5.249449139E-06
        22047.70c 4.734049768E-06
        22048.70c 4.690781303E-05
        22049.70c 3.442366163E-06
        22050.70c 3.296010329E-06
        24050.70c 6.626632931E-06
        24052.70c 1.276432221E-04
        24053.70c 1.447195267E-05
```

24054.70c 3.595142318E-06
25055.70c 8.097248629E-05
26054.70c 2.957894252E-05
26056.70c 4.639093973E-04
26057.70c 1.071922520E-05
26058.70c 1.415743190E-06
29063.70c 2.361354017E-04
29065.70c 1.052485436E-04
92234.70c 5.655740529E-05
92235.70c 5.271158317E-03
92236.70c 2.262313699E-05
92238.70c 3.054099136E-04
mt361 lwtr.60t
c total atom density = 8.00895E-02 a/b-cm
m362 $ 8.008950E-02
1001.70c 4.150781477E-01
8016.70c 2.251593619E-01
12024.70c 1.319598751E-03
12025.70c 1.670593589E-04
12026.70c 1.839317336E-04
13027.70c 3.488285119E-01
14028.70c 1.252024347E-03
14029.70c 6.339557870E-05
14030.70c 4.208267167E-05
22046.70c 5.247404673E-06
22047.70c 4.732206031E-06
22048.70c 4.688954417E-05
22049.70c 3.441025489E-06
22050.70c 3.294726655E-06
24050.70c 6.624052103E-06
24052.70c 1.275935098E-04
24053.70c 1.446631638E-05
24054.70c 3.593742143E-06
25055.70c 8.048521035E-05
26054.70c 2.930521595E-05
26056.70c 4.596158230E-04
26057.70c 1.061999430E-05
26058.70c 1.402643348E-06
29063.70c 2.345251343E-04
29065.70c 1.045308103E-04
92234.70c 6.769514373E-05
92235.70c 6.309191841E-03
92236.70c 2.707820733E-05
92238.70c 3.655535514E-04
mt362 lwtr.60t
c total atom density = 8.01228E-02 a/b-cm

```
m363     $  8.012280E-02
        1001.70c 4.149055891E-01
        8016.70c 2.282371390E-01
        12024.70c 1.319050160E-03
        12025.70c 1.669899081E-04
        12026.70c 1.838552685E-04
        13027.70c 3.447557742E-01
        14028.70c 1.242747290E-03
        14029.70c 6.292565444E-05
        14030.70c 4.177075379E-05
        22046.70c 5.245223192E-06
        22047.70c 4.730238732E-06
        22048.70c 4.687005099E-05
        22049.70c 3.439594966E-06
        22050.70c 3.293356952E-06
        24050.70c 6.621298315E-06
        24052.70c 1.275404659E-04
        24053.70c 1.446030236E-05
        24054.70c 3.592248132E-06
        25055.70c 7.996612106E-05
        26054.70c 2.901346218E-05
        26056.70c 4.550402294E-04
        26057.70c 1.051427231E-05
        26058.70c 1.388680772E-06
        29063.70c 2.328101191E-04
        29065.70c 1.037663360E-04
        92234.70c 7.955862160E-05
        92235.70c 7.414867627E-03
        92236.70c 3.182364833E-05
        92238.70c 4.296167563E-04
mt363     lwtr.60t
c       total atom density =  8.01530E-02 a/b-cm
m364     $  8.015300E-02
        1001.70c 4.147490712E-01
        8016.70c 2.310280357E-01
        12024.70c 1.318552565E-03
        12025.70c 1.669269133E-04
        12026.70c 1.837859114E-04
        13027.70c 3.410625360E-01
        14028.70c 1.234327441E-03
        14029.70c 6.249931174E-05
        14030.70c 4.148775754E-05
        22046.70c 5.243244499E-06
        22047.70c 4.728454310E-06
        22048.70c 4.685236986E-05
        22049.70c 3.438297423E-06
```

```
        22050.70c 3.292114575E-06
        24050.70c 6.618800514E-06
        24052.70c 1.274923529E-04
        24053.70c 1.445484740E-05
        24054.70c 3.590893002E-06
        25055.70c 7.949517309E-05
        26054.70c 2.874900220E-05
        26056.70c 4.508911802E-04
        26057.70c 1.041841922E-05
        26058.70c 1.376017632E-06
        29063.70c 2.312538537E-04
        29065.70c 1.030729430E-04
        92234.70c 9.031796872E-05
        92235.70c 8.417646762E-03
        92236.70c 3.612751187E-05
        92238.70c 4.877169812E-04
mt364     lwtr.60t
c       total atom density =  8.01437E-02 a/b-cm
m365     $  8.014370E-02
        1001.70c 4.147973069E-01
        8016.70c 2.301727393E-01
        12024.70c 1.318705914E-03
        12025.70c 1.669463270E-04
        12026.70c 1.838072859E-04
        13027.70c 3.421939905E-01
        14028.70c 1.236910361E-03
        14029.70c 6.263010854E-05
        14030.70c 4.157456033E-05
        22046.70c 5.243854293E-06
        22047.70c 4.729004233E-06
        22048.70c 4.685781883E-05
        22049.70c 3.438697300E-06
        22050.70c 3.292497451E-06
        24050.70c 6.619570287E-06
        24052.70c 1.275071804E-04
        24053.70c 1.445652851E-05
        24054.70c 3.591310626E-06
        25055.70c 7.963955068E-05
        26054.70c 2.883008108E-05
        26056.70c 4.521626791E-04
        26057.70c 1.044780527E-05
        26058.70c 1.379895984E-06
        29063.70c 2.317299417E-04
        29065.70c 1.032853205E-04
        92234.70c 8.702166354E-05
        92235.70c 8.110429423E-03
```

```
      92236.70c 3.480896488E-05
      92238.70c 4.699170330E-04
mt365     lwtr.60t
c       total atom density =  8.00985E-02 a/b-cm
m366     $  8.009850E-02
      1001.70c 4.150316390E-01
      8016.70c 2.259880820E-01
      12024.70c 1.319450892E-03
      12025.70c 1.670406402E-04
      12026.70c 1.839111244E-04
      13027.70c 3.477319779E-01
      14028.70c 1.249524465E-03
      14029.70c 6.326887256E-05
      14030.70c 4.199867897E-05
      22046.70c 5.246816711E-06
      22047.70c 4.731675796E-06
      22048.70c 4.688429029E-05
      22049.70c 3.440639928E-06
      22050.70c 3.294357487E-06
      24050.70c 6.623309891E-06
      24052.70c 1.275792132E-04
      24053.70c 1.446469546E-05
      24054.70c 3.593339471E-06
      25055.70c 8.034547803E-05
      26054.70c 2.922665002E-05
      26056.70c 4.583832776E-04
      26057.70c 1.059152543E-05
      26058.70c 1.398878126E-06
      29063.70c 2.340631425E-04
      29065.70c 1.043252115E-04
      92234.70c 7.088911783E-05
      92235.70c 6.606867629E-03
      92236.70c 2.835584689E-05
      92238.70c 3.828013112E-04
mt366     lwtr.60t
c       total atom density =  8.00555E-02 a/b-cm
m367     $  8.005550E-02
      1001.70c 4.152545507E-01
      8016.70c 2.220098021E-01
      12024.70c 1.320159564E-03
      12025.70c 1.671303571E-04
      12026.70c 1.840099023E-04
      13027.70c 3.529964722E-01
      14028.70c 1.261537714E-03
      14029.70c 6.387695590E-05
      14030.70c 4.240222209E-05
```

```
        22046.70c 5.249634754E-06
        22047.70c 4.734217159E-06
        22048.70c 4.690947164E-05
        22049.70c 3.442487881E-06
        22050.70c 3.296126872E-06
        24050.70c 6.626867242E-06
        24052.70c 1.276477354E-04
        24053.70c 1.447246438E-05
        24054.70c 3.595269438E-06
        25055.70c 8.101644589E-05
        26054.70c 2.960359702E-05
        26056.70c 4.642967934E-04
        26057.70c 1.072816079E-05
        26058.70c 1.416929960E-06
        29063.70c 2.362799068E-04
        29065.70c 1.053132228E-04
        92234.70c 5.555422712E-05
        92235.70c 5.177659664E-03
        92236.70c 2.222184074E-05
        92238.70c 2.999932262E-04
mt367     lwtr.60t
c       total atom density =  8.00271E-02 a/b-cm
m368     $  8.002710E-02
        1001.70c 4.154017194E-01
        8016.70c 2.193781522E-01
        12024.70c 1.320627436E-03
        12025.70c 1.671895891E-04
        12026.70c 1.840751165E-04
        13027.70c 3.564791884E-01
        14028.70c 1.269457278E-03
        14029.70c 6.427834092E-05
        14030.70c 4.266866449E-05
        22046.70c 5.251495256E-06
        22047.70c 4.735894994E-06
        22048.70c 4.692609664E-05
        22049.70c 3.443707919E-06
        22050.70c 3.297295039E-06
        24050.70c 6.629215843E-06
        24052.70c 1.276929746E-04
        24053.70c 1.447759351E-05
        24054.70c 3.596543623E-06
        25055.70c 8.146026792E-05
        26054.70c 2.985300775E-05
        26056.70c 4.682075734E-04
        26057.70c 1.081853357E-05
        26058.70c 1.428865754E-06
```

```
        29063.70c 2.377469270E-04
        29065.70c 1.059668376E-04
        92234.70c 4.541111007E-05
        92235.70c 4.232315658E-03
        92236.70c 1.816459398E-05
        92238.70c 2.452193946E-04
mt368     lwtr.60t
c       total atom density =  8.00013E-02 a/b-cm
m369     $  8.000130E-02
        1001.70c 4.155354944E-01
        8016.70c 2.169850918E-01
        12024.70c 1.321052728E-03
        12025.70c 1.672434304E-04
        12026.70c 1.841343956E-04
        13027.70c 3.596464366E-01
        14028.70c 1.276678476E-03
        14029.70c 6.464391015E-05
        14030.70c 4.291140154E-05
        22046.70c 5.253186435E-06
        22047.70c 4.737420130E-06
        22048.70c 4.694120860E-05
        22049.70c 3.444816923E-06
        22050.70c 3.298356892E-06
        24050.70c 6.631350700E-06
        24052.70c 1.277340965E-04
        24053.70c 1.448225584E-05
        24054.70c 3.597701845E-06
        25055.70c 8.186386983E-05
        26054.70c 3.007986787E-05
        26056.70c 4.717645464E-04
        26057.70c 1.090072872E-05
        26058.70c 1.439713227E-06
        29063.70c 2.390809693E-04
        29065.70c 1.065613284E-04
        92234.70c 3.618501495E-05
        92235.70c 3.372443143E-03
        92236.70c 1.447413098E-05
        92238.70c 1.953992057E-04
mt369     lwtr.60t
c
c       Outer Fuel Element  fueled region 7
c       total atom density =  8.00583E-02 a/b-cm
m371     $  8.005830E-02
        1001.70c 4.152398683E-01
        8016.70c 2.222692575E-01
        12024.70c 1.320112886E-03
```

```
        12025.70c 1.671244477E-04
        12026.70c 1.840033961E-04
        13027.70c 3.526529823E-01
        14028.70c 1.260743655E-03
        14029.70c 6.383672504E-05
        14030.70c 4.237561615E-05
        22046.70c 5.249449139E-06
        22047.70c 4.734049768E-06
        22048.70c 4.690781303E-05
        22049.70c 3.442366163E-06
        22050.70c 3.296010329E-06
        24050.70c 6.626632931E-06
        24052.70c 1.276432221E-04
        24053.70c 1.447195267E-05
        24054.70c 3.595142318E-06
        25055.70c 8.097248629E-05
        26054.70c 2.957894252E-05
        26056.70c 4.639093973E-04
        26057.70c 1.071922520E-05
        26058.70c 1.415743190E-06
        29063.70c 2.361354017E-04
        29065.70c 1.052485436E-04
        92234.70c 5.655740529E-05
        92235.70c 5.271158317E-03
        92236.70c 2.262313699E-05
        92238.70c 3.054099136E-04
mt371     lwtr.60t
c       total atom density =  8.00895E-02 a/b-cm
m372     $  8.008950E-02
        1001.70c 4.150781477E-01
        8016.70c 2.251593619E-01
        12024.70c 1.319598751E-03
        12025.70c 1.670593589E-04
        12026.70c 1.839317336E-04
        13027.70c 3.488285119E-01
        14028.70c 1.252024347E-03
        14029.70c 6.339557870E-05
        14030.70c 4.208267167E-05
        22046.70c 5.247404673E-06
        22047.70c 4.732206031E-06
        22048.70c 4.688954417E-05
        22049.70c 3.441025489E-06
        22050.70c 3.294726655E-06
        24050.70c 6.624052103E-06
        24052.70c 1.275935098E-04
        24053.70c 1.446631638E-05
```

```
      24054.70c 3.593742143E-06
      25055.70c 8.048521035E-05
      26054.70c 2.930521595E-05
      26056.70c 4.596158230E-04
      26057.70c 1.061999430E-05
      26058.70c 1.402643348E-06
      29063.70c 2.345251343E-04
      29065.70c 1.045308103E-04
      92234.70c 6.769514373E-05
      92235.70c 6.309191841E-03
      92236.70c 2.707820733E-05
      92238.70c 3.655535514E-04
mt372     lwtr.60t
c       total atom density =  8.01228E-02 a/b-cm
m373     $  8.012280E-02
      1001.70c 4.149055891E-01
      8016.70c 2.282371390E-01
      12024.70c 1.319050160E-03
      12025.70c 1.669899081E-04
      12026.70c 1.838552685E-04
      13027.70c 3.447557742E-01
      14028.70c 1.242747290E-03
      14029.70c 6.292565444E-05
      14030.70c 4.177075379E-05
      22046.70c 5.245223192E-06
      22047.70c 4.730238732E-06
      22048.70c 4.687005099E-05
      22049.70c 3.439594966E-06
      22050.70c 3.293356952E-06
      24050.70c 6.621298315E-06
      24052.70c 1.275404659E-04
      24053.70c 1.446030236E-05
      24054.70c 3.592248132E-06
      25055.70c 7.996612106E-05
      26054.70c 2.901346218E-05
      26056.70c 4.550402294E-04
      26057.70c 1.051427231E-05
      26058.70c 1.388680772E-06
      29063.70c 2.328101191E-04
      29065.70c 1.037663360E-04
      92234.70c 7.955862160E-05
      92235.70c 7.414867627E-03
      92236.70c 3.182364833E-05
      92238.70c 4.296167563E-04
mt373     lwtr.60t
c       total atom density =  8.01530E-02 a/b-cm
```

```
m374     $  8.015300E-02
        1001.70c 4.147490712E-01
        8016.70c 2.310280357E-01
        12024.70c 1.318552565E-03
        12025.70c 1.669269133E-04
        12026.70c 1.837859114E-04
        13027.70c 3.410625360E-01
        14028.70c 1.234327441E-03
        14029.70c 6.249931174E-05
        14030.70c 4.148775754E-05
        22046.70c 5.243244499E-06
        22047.70c 4.728454310E-06
        22048.70c 4.685236986E-05
        22049.70c 3.438297423E-06
        22050.70c 3.292114575E-06
        24050.70c 6.618800514E-06
        24052.70c 1.274923529E-04
        24053.70c 1.445484740E-05
        24054.70c 3.590893002E-06
        25055.70c 7.949517309E-05
        26054.70c 2.874900220E-05
        26056.70c 4.508911802E-04
        26057.70c 1.041841922E-05
        26058.70c 1.376017632E-06
        29063.70c 2.312538537E-04
        29065.70c 1.030729430E-04
        92234.70c 9.031796872E-05
        92235.70c 8.417646762E-03
        92236.70c 3.612751187E-05
        92238.70c 4.877169812E-04
mt374     lwtr.60t
c       total atom density =  8.01437E-02 a/b-cm
m375     $  8.014370E-02
        1001.70c 4.147973069E-01
        8016.70c 2.301727393E-01
        12024.70c 1.318705914E-03
        12025.70c 1.669463270E-04
        12026.70c 1.838072859E-04
        13027.70c 3.421939905E-01
        14028.70c 1.236910361E-03
        14029.70c 6.263010854E-05
        14030.70c 4.157456033E-05
        22046.70c 5.243854293E-06
        22047.70c 4.729004233E-06
        22048.70c 4.685781883E-05
        22049.70c 3.438697300E-06
```

```
        22050.70c 3.292497451E-06
        24050.70c 6.619570287E-06
        24052.70c 1.275071804E-04
        24053.70c 1.445652851E-05
        24054.70c 3.591310626E-06
        25055.70c 7.963955068E-05
        26054.70c 2.883008108E-05
        26056.70c 4.521626791E-04
        26057.70c 1.044780527E-05
        26058.70c 1.379895984E-06
        29063.70c 2.317299417E-04
        29065.70c 1.032853205E-04
        92234.70c 8.702166354E-05
        92235.70c 8.110429423E-03
        92236.70c 3.480896488E-05
        92238.70c 4.699170330E-04
mt375     lwtr.60t
c       total atom density =  8.00985E-02 a/b-cm
m376     $  8.009850E-02
        1001.70c 4.150316390E-01
        8016.70c 2.259880820E-01
        12024.70c 1.319450892E-03
        12025.70c 1.670406402E-04
        12026.70c 1.839111244E-04
        13027.70c 3.477319779E-01
        14028.70c 1.249524465E-03
        14029.70c 6.326887256E-05
        14030.70c 4.199867897E-05
        22046.70c 5.246816711E-06
        22047.70c 4.731675796E-06
        22048.70c 4.688429029E-05
        22049.70c 3.440639928E-06
        22050.70c 3.294357487E-06
        24050.70c 6.623309891E-06
        24052.70c 1.275792132E-04
        24053.70c 1.446469546E-05
        24054.70c 3.593339471E-06
        25055.70c 8.034547803E-05
        26054.70c 2.922665002E-05
        26056.70c 4.583832776E-04
        26057.70c 1.059152543E-05
        26058.70c 1.398878126E-06
        29063.70c 2.340631425E-04
        29065.70c 1.043252115E-04
        92234.70c 7.088911783E-05
        92235.70c 6.606867629E-03
```

```
        92236.70c 2.835584689E-05
        92238.70c 3.828013112E-04
mt376     lwtr.60t
c       total atom density =  8.00555E-02 a/b-cm
m377     $  8.005550E-02
        1001.70c 4.152545507E-01
        8016.70c 2.220098021E-01
        12024.70c 1.320159564E-03
        12025.70c 1.671303571E-04
        12026.70c 1.840099023E-04
        13027.70c 3.529964722E-01
        14028.70c 1.261537714E-03
        14029.70c 6.387695590E-05
        14030.70c 4.240222209E-05
        22046.70c 5.249634754E-06
        22047.70c 4.734217159E-06
        22048.70c 4.690947164E-05
        22049.70c 3.442487881E-06
        22050.70c 3.296126872E-06
        24050.70c 6.626867242E-06
        24052.70c 1.276477354E-04
        24053.70c 1.447246438E-05
        24054.70c 3.595269438E-06
        25055.70c 8.101644589E-05
        26054.70c 2.960359702E-05
        26056.70c 4.642967934E-04
        26057.70c 1.072816079E-05
        26058.70c 1.416929960E-06
        29063.70c 2.362799068E-04
        29065.70c 1.053132228E-04
        92234.70c 5.555422712E-05
        92235.70c 5.177659664E-03
        92236.70c 2.222184074E-05
        92238.70c 2.999932262E-04
mt377     lwtr.60t
c       total atom density =  8.00271E-02 a/b-cm
m378     $  8.002710E-02
        1001.70c 4.154017194E-01
        8016.70c 2.193781522E-01
        12024.70c 1.320627436E-03
        12025.70c 1.671895891E-04
        12026.70c 1.840751165E-04
        13027.70c 3.564791884E-01
        14028.70c 1.269457278E-03
        14029.70c 6.427834092E-05
        14030.70c 4.266866449E-05
```

22046.70c 5.251495256E-06
22047.70c 4.735894994E-06
22048.70c 4.692609664E-05
22049.70c 3.443707919E-06
22050.70c 3.297295039E-06
24050.70c 6.629215843E-06
24052.70c 1.276929746E-04
24053.70c 1.447759351E-05
24054.70c 3.596543623E-06
25055.70c 8.146026792E-05
26054.70c 2.985300775E-05
26056.70c 4.682075734E-04
26057.70c 1.081853357E-05
26058.70c 1.428865754E-06
29063.70c 2.377469270E-04
29065.70c 1.059668376E-04
92234.70c 4.541111007E-05
92235.70c 4.232315658E-03
92236.70c 1.816459398E-05
92238.70c 2.452193946E-04
mt378 lwtr.60t
c total atom density = 8.00013E-02 a/b-cm
m379 $ 8.000130E-02
1001.70c 4.155354944E-01
8016.70c 2.169850918E-01
12024.70c 1.321052728E-03
12025.70c 1.672434304E-04
12026.70c 1.841343956E-04
13027.70c 3.596464366E-01
14028.70c 1.276678476E-03
14029.70c 6.464391015E-05
14030.70c 4.291140154E-05
22046.70c 5.253186435E-06
22047.70c 4.737420130E-06
22048.70c 4.694120860E-05
22049.70c 3.444816923E-06
22050.70c 3.298356892E-06
24050.70c 6.631350700E-06
24052.70c 1.277340965E-04
24053.70c 1.448225584E-05
24054.70c 3.597701845E-06
25055.70c 8.186386983E-05
26054.70c 3.007986787E-05
26056.70c 4.717645464E-04
26057.70c 1.090072872E-05
26058.70c 1.439713227E-06

```
        29063.70c 2.390809693E-04
        29065.70c 1.065613284E-04
        92234.70c 3.618501495E-05
        92235.70c 3.372443143E-03
        92236.70c 1.447413098E-05
        92238.70c 1.953992057E-04
mt379     lwtr.60t
c
c       Outer Fuel Element  fueled region 8
c       total atom density =  8.00583E-02 a/b-cm
m381     $  8.005830E-02
        1001.70c 4.152398683E-01
        8016.70c 2.222692575E-01
        12024.70c 1.320112886E-03
        12025.70c 1.671244477E-04
        12026.70c 1.840033961E-04
        13027.70c 3.526529823E-01
        14028.70c 1.260743655E-03
        14029.70c 6.383672504E-05
        14030.70c 4.237561615E-05
        22046.70c 5.249449139E-06
        22047.70c 4.734049768E-06
        22048.70c 4.690781303E-05
        22049.70c 3.442366163E-06
        22050.70c 3.296010329E-06
        24050.70c 6.626632931E-06
        24052.70c 1.276432221E-04
        24053.70c 1.447195267E-05
        24054.70c 3.595142318E-06
        25055.70c 8.097248629E-05
        26054.70c 2.957894252E-05
        26056.70c 4.639093973E-04
        26057.70c 1.071922520E-05
        26058.70c 1.415743190E-06
        29063.70c 2.361354017E-04
        29065.70c 1.052485436E-04
        92234.70c 5.655740529E-05
        92235.70c 5.271158317E-03
        92236.70c 2.262313699E-05
        92238.70c 3.054099136E-04
mt381     lwtr.60t
c       total atom density =  8.00895E-02 a/b-cm
m382     $  8.008950E-02
        1001.70c 4.150781477E-01
        8016.70c 2.251593619E-01
        12024.70c 1.319598751E-03
```

12025.70c 1.670593589E-04
12026.70c 1.839317336E-04
13027.70c 3.488285119E-01
14028.70c 1.252024347E-03
14029.70c 6.339557870E-05
14030.70c 4.208267167E-05
22046.70c 5.247404673E-06
22047.70c 4.732206031E-06
22048.70c 4.688954417E-05
22049.70c 3.441025489E-06
22050.70c 3.294726655E-06
24050.70c 6.624052103E-06
24052.70c 1.275935098E-04
24053.70c 1.446631638E-05
24054.70c 3.593742143E-06
25055.70c 8.048521035E-05
26054.70c 2.930521595E-05
26056.70c 4.596158230E-04
26057.70c 1.061999430E-05
26058.70c 1.402643348E-06
29063.70c 2.345251343E-04
29065.70c 1.045308103E-04
92234.70c 6.769514373E-05
92235.70c 6.309191841E-03
92236.70c 2.707820733E-05
92238.70c 3.655535514E-04
mt382 lwtr.60t
c total atom density = 8.01228E-02 a/b-cm
m383 $ 8.012280E-02
1001.70c 4.149055891E-01
8016.70c 2.282371390E-01
12024.70c 1.319050160E-03
12025.70c 1.669899081E-04
12026.70c 1.838552685E-04
13027.70c 3.447557742E-01
14028.70c 1.242747290E-03
14029.70c 6.292565444E-05
14030.70c 4.177075379E-05
22046.70c 5.245223192E-06
22047.70c 4.730238732E-06
22048.70c 4.687005099E-05
22049.70c 3.439594966E-06
22050.70c 3.293356952E-06
24050.70c 6.621298315E-06
24052.70c 1.275404659E-04
24053.70c 1.446030236E-05

```
       24054.70c 3.592248132E-06
       25055.70c 7.996612106E-05
       26054.70c 2.901346218E-05
       26056.70c 4.550402294E-04
       26057.70c 1.051427231E-05
       26058.70c 1.388680772E-06
       29063.70c 2.328101191E-04
       29065.70c 1.037663360E-04
       92234.70c 7.955862160E-05
       92235.70c 7.414867627E-03
       92236.70c 3.182364833E-05
       92238.70c 4.296167563E-04
mt383     lwtr.60t
c       total atom density =  8.01530E-02 a/b-cm
m384     $  8.015300E-02
       1001.70c 4.147490712E-01
       8016.70c 2.310280357E-01
       12024.70c 1.318552565E-03
       12025.70c 1.669269133E-04
       12026.70c 1.837859114E-04
       13027.70c 3.410625360E-01
       14028.70c 1.234327441E-03
       14029.70c 6.249931174E-05
       14030.70c 4.148775754E-05
       22046.70c 5.243244499E-06
       22047.70c 4.728454310E-06
       22048.70c 4.685236986E-05
       22049.70c 3.438297423E-06
       22050.70c 3.292114575E-06
       24050.70c 6.618800514E-06
       24052.70c 1.274923529E-04
       24053.70c 1.445484740E-05
       24054.70c 3.590893002E-06
       25055.70c 7.949517309E-05
       26054.70c 2.874900220E-05
       26056.70c 4.508911802E-04
       26057.70c 1.041841922E-05
       26058.70c 1.376017632E-06
       29063.70c 2.312538537E-04
       29065.70c 1.030729430E-04
       92234.70c 9.031796872E-05
       92235.70c 8.417646762E-03
       92236.70c 3.612751187E-05
       92238.70c 4.877169812E-04
mt384     lwtr.60t
c       total atom density =  8.01437E-02 a/b-cm
```

m385 $ 8.014370E-02
1001.70c 4.147973069E-01
8016.70c 2.301727393E-01
12024.70c 1.318705914E-03
12025.70c 1.669463270E-04
12026.70c 1.838072859E-04
13027.70c 3.421939905E-01
14028.70c 1.236910361E-03
14029.70c 6.263010854E-05
14030.70c 4.157456033E-05
22046.70c 5.243854293E-06
22047.70c 4.729004233E-06
22048.70c 4.685781883E-05
22049.70c 3.438697300E-06
22050.70c 3.292497451E-06
24050.70c 6.619570287E-06
24052.70c 1.275071804E-04
24053.70c 1.445652851E-05
24054.70c 3.591310626E-06
25055.70c 7.963955068E-05
26054.70c 2.883008108E-05
26056.70c 4.521626791E-04
26057.70c 1.044780527E-05
26058.70c 1.379895984E-06
29063.70c 2.317299417E-04
29065.70c 1.032853205E-04
92234.70c 8.702166354E-05
92235.70c 8.110429423E-03
92236.70c 3.480896488E-05
92238.70c 4.699170330E-04
mt385 lwtr.60t
c total atom density = 8.00985E-02 a/b-cm
m386 $ 8.009850E-02
1001.70c 4.150316390E-01
8016.70c 2.259880820E-01
12024.70c 1.319450892E-03
12025.70c 1.670406402E-04
12026.70c 1.839111244E-04
13027.70c 3.477319779E-01
14028.70c 1.249524465E-03
14029.70c 6.326887256E-05
14030.70c 4.199867897E-05
22046.70c 5.246816711E-06
22047.70c 4.731675796E-06
22048.70c 4.688429029E-05
22049.70c 3.440639928E-06

```
        22050.70c 3.294357487E-06
        24050.70c 6.623309891E-06
        24052.70c 1.275792132E-04
        24053.70c 1.446469546E-05
        24054.70c 3.593339471E-06
        25055.70c 8.034547803E-05
        26054.70c 2.922665002E-05
        26056.70c 4.583832776E-04
        26057.70c 1.059152543E-05
        26058.70c 1.398878126E-06
        29063.70c 2.340631425E-04
        29065.70c 1.043252115E-04
        92234.70c 7.088911783E-05
        92235.70c 6.606867629E-03
        92236.70c 2.835584689E-05
        92238.70c 3.828013112E-04
mt386     lwtr.60t
c       total atom density =  8.00555E-02 a/b-cm
m387     $  8.005550E-02
        1001.70c 4.152545507E-01
        8016.70c 2.220098021E-01
        12024.70c 1.320159564E-03
        12025.70c 1.671303571E-04
        12026.70c 1.840099023E-04
        13027.70c 3.529964722E-01
        14028.70c 1.261537714E-03
        14029.70c 6.387695590E-05
        14030.70c 4.240222209E-05
        22046.70c 5.249634754E-06
        22047.70c 4.734217159E-06
        22048.70c 4.690947164E-05
        22049.70c 3.442487881E-06
        22050.70c 3.296126872E-06
        24050.70c 6.626867242E-06
        24052.70c 1.276477354E-04
        24053.70c 1.447246438E-05
        24054.70c 3.595269438E-06
        25055.70c 8.101644589E-05
        26054.70c 2.960359702E-05
        26056.70c 4.642967934E-04
        26057.70c 1.072816079E-05
        26058.70c 1.416929960E-06
        29063.70c 2.362799068E-04
        29065.70c 1.053132228E-04
        92234.70c 5.555422712E-05
        92235.70c 5.177659664E-03
```

92236.70c 2.222184074E-05
92238.70c 2.999932262E-04
mt387 lwtr.60t
c total atom density = 8.00271E-02 a/b-cm
m388 $ 8.002710E-02
1001.70c 4.154017194E-01
8016.70c 2.193781522E-01
12024.70c 1.320627436E-03
12025.70c 1.671895891E-04
12026.70c 1.840751165E-04
13027.70c 3.564791884E-01
14028.70c 1.269457278E-03
14029.70c 6.427834092E-05
14030.70c 4.266866449E-05
22046.70c 5.251495256E-06
22047.70c 4.735894994E-06
22048.70c 4.692609664E-05
22049.70c 3.443707919E-06
22050.70c 3.297295039E-06
24050.70c 6.629215843E-06
24052.70c 1.276929746E-04
24053.70c 1.447759351E-05
24054.70c 3.596543623E-06
25055.70c 8.146026792E-05
26054.70c 2.985300775E-05
26056.70c 4.682075734E-04
26057.70c 1.081853357E-05
26058.70c 1.428865754E-06
29063.70c 2.377469270E-04
29065.70c 1.059668376E-04
92234.70c 4.541111007E-05
92235.70c 4.232315658E-03
92236.70c 1.816459398E-05
92238.70c 2.452193946E-04
mt388 lwtr.60t
c total atom density = 8.00013E-02 a/b-cm
m389 $ 8.000130E-02
1001.70c 4.155354944E-01
8016.70c 2.169850918E-01
12024.70c 1.321052728E-03
12025.70c 1.672434304E-04
12026.70c 1.841343956E-04
13027.70c 3.596464366E-01
14028.70c 1.276678476E-03
14029.70c 6.464391015E-05
14030.70c 4.291140154E-05

```
        22046.70c 5.253186435E-06
        22047.70c 4.737420130E-06
        22048.70c 4.694120860E-05
        22049.70c 3.444816923E-06
        22050.70c 3.298356892E-06
        24050.70c 6.631350700E-06
        24052.70c 1.277340965E-04
        24053.70c 1.448225584E-05
        24054.70c 3.597701845E-06
        25055.70c 8.186386983E-05
        26054.70c 3.007986787E-05
        26056.70c 4.717645464E-04
        26057.70c 1.090072872E-05
        26058.70c 1.439713227E-06
        29063.70c 2.390809693E-04
        29065.70c 1.065613284E-04
        92234.70c 3.618501495E-05
        92235.70c 3.372443143E-03
        92236.70c 1.447413098E-05
        92238.70c 1.953992057E-04
mt389     lwtr.60t
c
c       Outer Fuel Element  fueled region 9
c       total atom density =  8.00583E-02 a/b-cm
m391     $  8.005830E-02
        1001.70c 4.152398683E-01
        8016.70c 2.222692575E-01
        12024.70c 1.320112886E-03
        12025.70c 1.671244477E-04
        12026.70c 1.840033961E-04
        13027.70c 3.526529823E-01
        14028.70c 1.260743655E-03
        14029.70c 6.383672504E-05
        14030.70c 4.237561615E-05
        22046.70c 5.249449139E-06
        22047.70c 4.734049768E-06
        22048.70c 4.690781303E-05
        22049.70c 3.442366163E-06
        22050.70c 3.296010329E-06
        24050.70c 6.626632931E-06
        24052.70c 1.276432221E-04
        24053.70c 1.447195267E-05
        24054.70c 3.595142318E-06
        25055.70c 8.097248629E-05
        26054.70c 2.957894252E-05
        26056.70c 4.639093973E-04
```

```
        26057.70c 1.071922520E-05
        26058.70c 1.415743190E-06
        29063.70c 2.361354017E-04
        29065.70c 1.052485436E-04
        92234.70c 5.655740529E-05
        92235.70c 5.271158317E-03
        92236.70c 2.262313699E-05
        92238.70c 3.054099136E-04
mt391     lwtr.60t
c       total atom density =  8.00895E-02 a/b-cm
m392     $  8.008950E-02
        1001.70c 4.150781477E-01
        8016.70c 2.251593619E-01
        12024.70c 1.319598751E-03
        12025.70c 1.670593589E-04
        12026.70c 1.839317336E-04
        13027.70c 3.488285119E-01
        14028.70c 1.252024347E-03
        14029.70c 6.339557870E-05
        14030.70c 4.208267167E-05
        22046.70c 5.247404673E-06
        22047.70c 4.732206031E-06
        22048.70c 4.688954417E-05
        22049.70c 3.441025489E-06
        22050.70c 3.294726655E-06
        24050.70c 6.624052103E-06
        24052.70c 1.275935098E-04
        24053.70c 1.446631638E-05
        24054.70c 3.593742143E-06
        25055.70c 8.048521035E-05
        26054.70c 2.930521595E-05
        26056.70c 4.596158230E-04
        26057.70c 1.061999430E-05
        26058.70c 1.402643348E-06
        29063.70c 2.345251343E-04
        29065.70c 1.045308103E-04
        92234.70c 6.769514373E-05
        92235.70c 6.309191841E-03
        92236.70c 2.707820733E-05
        92238.70c 3.655535514E-04
mt392     lwtr.60t
c       total atom density =  8.01228E-02 a/b-cm
m393     $  8.012280E-02
        1001.70c 4.149055891E-01
        8016.70c 2.282371390E-01
        12024.70c 1.319050160E-03
```

12025.70c 1.669899081E-04
12026.70c 1.838552685E-04
13027.70c 3.447557742E-01
14028.70c 1.242747290E-03
14029.70c 6.292565444E-05
14030.70c 4.177075379E-05
22046.70c 5.245223192E-06
22047.70c 4.730238732E-06
22048.70c 4.687005099E-05
22049.70c 3.439594966E-06
22050.70c 3.293356952E-06
24050.70c 6.621298315E-06
24052.70c 1.275404659E-04
24053.70c 1.446030236E-05
24054.70c 3.592248132E-06
25055.70c 7.996612106E-05
26054.70c 2.901346218E-05
26056.70c 4.550402294E-04
26057.70c 1.051427231E-05
26058.70c 1.388680772E-06
29063.70c 2.328101191E-04
29065.70c 1.037663360E-04
92234.70c 7.955862160E-05
92235.70c 7.414867627E-03
92236.70c 3.182364833E-05
92238.70c 4.296167563E-04
mt393 lwtr.60t
c total atom density = 8.01530E-02 a/b-cm
m394 $ 8.015300E-02
1001.70c 4.147490712E-01
8016.70c 2.310280357E-01
12024.70c 1.318552565E-03
12025.70c 1.669269133E-04
12026.70c 1.837859114E-04
13027.70c 3.410625360E-01
14028.70c 1.234327441E-03
14029.70c 6.249931174E-05
14030.70c 4.148775754E-05
22046.70c 5.243244499E-06
22047.70c 4.728454310E-06
22048.70c 4.685236986E-05
22049.70c 3.438297423E-06
22050.70c 3.292114575E-06
24050.70c 6.618800514E-06
24052.70c 1.274923529E-04
24053.70c 1.445484740E-05

```
        24054.70c 3.590893002E-06
        25055.70c 7.949517309E-05
        26054.70c 2.874900220E-05
        26056.70c 4.508911802E-04
        26057.70c 1.041841922E-05
        26058.70c 1.376017632E-06
        29063.70c 2.312538537E-04
        29065.70c 1.030729430E-04
        92234.70c 9.031796872E-05
        92235.70c 8.417646762E-03
        92236.70c 3.612751187E-05
        92238.70c 4.877169812E-04
mt394     lwtr.60t
c       total atom density =  8.01437E-02 a/b-cm
m395      $  8.014370E-02
        1001.70c 4.147973069E-01
        8016.70c 2.301727393E-01
        12024.70c 1.318705914E-03
        12025.70c 1.669463270E-04
        12026.70c 1.838072859E-04
        13027.70c 3.421939905E-01
        14028.70c 1.236910361E-03
        14029.70c 6.263010854E-05
        14030.70c 4.157456033E-05
        22046.70c 5.243854293E-06
        22047.70c 4.729004233E-06
        22048.70c 4.685781883E-05
        22049.70c 3.438697300E-06
        22050.70c 3.292497451E-06
        24050.70c 6.619570287E-06
        24052.70c 1.275071804E-04
        24053.70c 1.445652851E-05
        24054.70c 3.591310626E-06
        25055.70c 7.963955068E-05
        26054.70c 2.883008108E-05
        26056.70c 4.521626791E-04
        26057.70c 1.044780527E-05
        26058.70c 1.379895984E-06
        29063.70c 2.317299417E-04
        29065.70c 1.032853205E-04
        92234.70c 8.702166354E-05
        92235.70c 8.110429423E-03
        92236.70c 3.480896488E-05
        92238.70c 4.699170330E-04
mt395     lwtr.60t
c       total atom density =  8.00985E-02 a/b-cm
```

```
m396     $  8.009850E-02
        1001.70c 4.150316390E-01
        8016.70c 2.259880820E-01
        12024.70c 1.319450892E-03
        12025.70c 1.670406402E-04
        12026.70c 1.839111244E-04
        13027.70c 3.477319779E-01
        14028.70c 1.249524465E-03
        14029.70c 6.326887256E-05
        14030.70c 4.199867897E-05
        22046.70c 5.246816711E-06
        22047.70c 4.731675796E-06
        22048.70c 4.688429029E-05
        22049.70c 3.440639928E-06
        22050.70c 3.294357487E-06
        24050.70c 6.623309891E-06
        24052.70c 1.275792132E-04
        24053.70c 1.446469546E-05
        24054.70c 3.593339471E-06
        25055.70c 8.034547803E-05
        26054.70c 2.922665002E-05
        26056.70c 4.583832776E-04
        26057.70c 1.059152543E-05
        26058.70c 1.398878126E-06
        29063.70c 2.340631425E-04
        29065.70c 1.043252115E-04
        92234.70c 7.088911783E-05
        92235.70c 6.606867629E-03
        92236.70c 2.835584689E-05
        92238.70c 3.828013112E-04
mt396     lwtr.60t
c       total atom density =  8.00555E-02 a/b-cm
m397     $  8.005550E-02
        1001.70c 4.152545507E-01
        8016.70c 2.220098021E-01
        12024.70c 1.320159564E-03
        12025.70c 1.671303571E-04
        12026.70c 1.840099023E-04
        13027.70c 3.529964722E-01
        14028.70c 1.261537714E-03
        14029.70c 6.387695590E-05
        14030.70c 4.240222209E-05
        22046.70c 5.249634754E-06
        22047.70c 4.734217159E-06
        22048.70c 4.690947164E-05
        22049.70c 3.442487881E-06
```

```
        22050.70c 3.296126872E-06
        24050.70c 6.626867242E-06
        24052.70c 1.276477354E-04
        24053.70c 1.447246438E-05
        24054.70c 3.595269438E-06
        25055.70c 8.101644589E-05
        26054.70c 2.960359702E-05
        26056.70c 4.642967934E-04
        26057.70c 1.072816079E-05
        26058.70c 1.416929960E-06
        29063.70c 2.362799068E-04
        29065.70c 1.053132228E-04
        92234.70c 5.555422712E-05
        92235.70c 5.177659664E-03
        92236.70c 2.222184074E-05
        92238.70c 2.999932262E-04
mt397     lwtr.60t
c       total atom density =  8.00271E-02 a/b-cm
m398     $  8.002710E-02
        1001.70c 4.154017194E-01
        8016.70c 2.193781522E-01
        12024.70c 1.320627436E-03
        12025.70c 1.671895891E-04
        12026.70c 1.840751165E-04
        13027.70c 3.564791884E-01
        14028.70c 1.269457278E-03
        14029.70c 6.427834092E-05
        14030.70c 4.266866449E-05
        22046.70c 5.251495256E-06
        22047.70c 4.735894994E-06
        22048.70c 4.692609664E-05
        22049.70c 3.443707919E-06
        22050.70c 3.297295039E-06
        24050.70c 6.629215843E-06
        24052.70c 1.276929746E-04
        24053.70c 1.447759351E-05
        24054.70c 3.596543623E-06
        25055.70c 8.146026792E-05
        26054.70c 2.985300775E-05
        26056.70c 4.682075734E-04
        26057.70c 1.081853357E-05
        26058.70c 1.428865754E-06
        29063.70c 2.377469270E-04
        29065.70c 1.059668376E-04
        92234.70c 4.541111007E-05
        92235.70c 4.232315658E-03
```

```
        92236.70c 1.816459398E-05
        92238.70c 2.452193946E-04
mt398     lwtr.60t
c       total atom density =  8.00013E-02 a/b-cm
m399     $  8.000130E-02
        1001.70c 4.155354944E-01
        8016.70c 2.169850918E-01
        12024.70c 1.321052728E-03
        12025.70c 1.672434304E-04
        12026.70c 1.841343956E-04
        13027.70c 3.596464366E-01
        14028.70c 1.276678476E-03
        14029.70c 6.464391015E-05
        14030.70c 4.291140154E-05
        22046.70c 5.253186435E-06
        22047.70c 4.737420130E-06
        22048.70c 4.694120860E-05
        22049.70c 3.444816923E-06
        22050.70c 3.298356892E-06
        24050.70c 6.631350700E-06
        24052.70c 1.277340965E-04
        24053.70c 1.448225584E-05
        24054.70c 3.597701845E-06
        25055.70c 8.186386983E-05
        26054.70c 3.007986787E-05
        26056.70c 4.717645464E-04
        26057.70c 1.090072872E-05
        26058.70c 1.439713227E-06
        29063.70c 2.390809693E-04
        29065.70c 1.065613284E-04
        92234.70c 3.618501495E-05
        92235.70c 3.372443143E-03
        92236.70c 1.447413098E-05
        92238.70c 1.953992057E-04
mt399     lwtr.60t
c
c       Outer Fuel Element  fueled region 0 Central
c       total atom density =  8.00583E-02 a/b-cm
m301     $  8.005830E-02
        1001.70c 4.152398683E-01
        8016.70c 2.222692575E-01
        12024.70c 1.320112886E-03
        12025.70c 1.671244477E-04
        12026.70c 1.840033961E-04
        13027.70c 3.526529823E-01
        14028.70c 1.260743655E-03
```

```
        14029.70c 6.383672504E-05
        14030.70c 4.237561615E-05
        22046.70c 5.249449139E-06
        22047.70c 4.734049768E-06
        22048.70c 4.690781303E-05
        22049.70c 3.442366163E-06
        22050.70c 3.296010329E-06
        24050.70c 6.626632931E-06
        24052.70c 1.276432221E-04
        24053.70c 1.447195267E-05
        24054.70c 3.595142318E-06
        25055.70c 8.097248629E-05
        26054.70c 2.957894252E-05
        26056.70c 4.639093973E-04
        26057.70c 1.071922520E-05
        26058.70c 1.415743190E-06
        29063.70c 2.361354017E-04
        29065.70c 1.052485436E-04
        92234.70c 5.655740529E-05
        92235.70c 5.271158317E-03
        92236.70c 2.262313699E-05
        92238.70c 3.054099136E-04
mt301     lwtr.60t
c       total atom density =  8.00895E-02 a/b-cm
m302     $  8.008950E-02
        1001.70c 4.150781477E-01
        8016.70c 2.251593619E-01
        12024.70c 1.319598751E-03
        12025.70c 1.670593589E-04
        12026.70c 1.839317336E-04
        13027.70c 3.488285119E-01
        14028.70c 1.252024347E-03
        14029.70c 6.339557870E-05
        14030.70c 4.208267167E-05
        22046.70c 5.247404673E-06
        22047.70c 4.732206031E-06
        22048.70c 4.688954417E-05
        22049.70c 3.441025489E-06
        22050.70c 3.294726655E-06
        24050.70c 6.624052103E-06
        24052.70c 1.275935098E-04
        24053.70c 1.446631638E-05
        24054.70c 3.593742143E-06
        25055.70c 8.048521035E-05
        26054.70c 2.930521595E-05
        26056.70c 4.596158230E-04
```

```
        26057.70c 1.061999430E-05
        26058.70c 1.402643348E-06
        29063.70c 2.345251343E-04
        29065.70c 1.045308103E-04
        92234.70c 6.769514373E-05
        92235.70c 6.309191841E-03
        92236.70c 2.707820733E-05
        92238.70c 3.655535514E-04
mt302     lwtr.60t
c       total atom density =  8.01228E-02 a/b-cm
m303     $  8.012280E-02
        1001.70c 4.149055891E-01
        8016.70c 2.282371390E-01
        12024.70c 1.319050160E-03
        12025.70c 1.669899081E-04
        12026.70c 1.838552685E-04
        13027.70c 3.447557742E-01
        14028.70c 1.242747290E-03
        14029.70c 6.292565444E-05
        14030.70c 4.177075379E-05
        22046.70c 5.245223192E-06
        22047.70c 4.730238732E-06
        22048.70c 4.687005099E-05
        22049.70c 3.439594966E-06
        22050.70c 3.293356952E-06
        24050.70c 6.621298315E-06
        24052.70c 1.275404659E-04
        24053.70c 1.446030236E-05
        24054.70c 3.592248132E-06
        25055.70c 7.996612106E-05
        26054.70c 2.901346218E-05
        26056.70c 4.550402294E-04
        26057.70c 1.051427231E-05
        26058.70c 1.388680772E-06
        29063.70c 2.328101191E-04
        29065.70c 1.037663360E-04
        92234.70c 7.955862160E-05
        92235.70c 7.414867627E-03
        92236.70c 3.182364833E-05
        92238.70c 4.296167563E-04
mt303     lwtr.60t
c       total atom density =  8.01530E-02 a/b-cm
m304     $  8.015300E-02
        1001.70c 4.147490712E-01
        8016.70c 2.310280357E-01
        12024.70c 1.318552565E-03
```

```
        12025.70c 1.669269133E-04
        12026.70c 1.837859114E-04
        13027.70c 3.410625360E-01
        14028.70c 1.234327441E-03
        14029.70c 6.249931174E-05
        14030.70c 4.148775754E-05
        22046.70c 5.243244499E-06
        22047.70c 4.728454310E-06
        22048.70c 4.685236986E-05
        22049.70c 3.438297423E-06
        22050.70c 3.292114575E-06
        24050.70c 6.618800514E-06
        24052.70c 1.274923529E-04
        24053.70c 1.445484740E-05
        24054.70c 3.590893002E-06
        25055.70c 7.949517309E-05
        26054.70c 2.874900220E-05
        26056.70c 4.508911802E-04
        26057.70c 1.041841922E-05
        26058.70c 1.376017632E-06
        29063.70c 2.312538537E-04
        29065.70c 1.030729430E-04
        92234.70c 9.031796872E-05
        92235.70c 8.417646762E-03
        92236.70c 3.612751187E-05
        92238.70c 4.877169812E-04
mt304     lwtr.60t
c       total atom density =  8.01437E-02 a/b-cm
m305     $  8.014370E-02
        1001.70c 4.147973069E-01
        8016.70c 2.301727393E-01
        12024.70c 1.318705914E-03
        12025.70c 1.669463270E-04
        12026.70c 1.838072859E-04
        13027.70c 3.421939905E-01
        14028.70c 1.236910361E-03
        14029.70c 6.263010854E-05
        14030.70c 4.157456033E-05
        22046.70c 5.243854293E-06
        22047.70c 4.729004233E-06
        22048.70c 4.685781883E-05
        22049.70c 3.438697300E-06
        22050.70c 3.292497451E-06
        24050.70c 6.619570287E-06
        24052.70c 1.275071804E-04
        24053.70c 1.445652851E-05
```

```
      24054.70c 3.591310626E-06
      25055.70c 7.963955068E-05
      26054.70c 2.883008108E-05
      26056.70c 4.521626791E-04
      26057.70c 1.044780527E-05
      26058.70c 1.379895984E-06
      29063.70c 2.317299417E-04
      29065.70c 1.032853205E-04
      92234.70c 8.702166354E-05
      92235.70c 8.110429423E-03
      92236.70c 3.480896488E-05
      92238.70c 4.699170330E-04
mt305    lwtr.60t
c      total atom density =  8.00985E-02 a/b-cm
m306     $  8.009850E-02
      1001.70c 4.150316390E-01
      8016.70c 2.259880820E-01
      12024.70c 1.319450892E-03
      12025.70c 1.670406402E-04
      12026.70c 1.839111244E-04
      13027.70c 3.477319779E-01
      14028.70c 1.249524465E-03
      14029.70c 6.326887256E-05
      14030.70c 4.199867897E-05
      22046.70c 5.246816711E-06
      22047.70c 4.731675796E-06
      22048.70c 4.688429029E-05
      22049.70c 3.440639928E-06
      22050.70c 3.294357487E-06
      24050.70c 6.623309891E-06
      24052.70c 1.275792132E-04
      24053.70c 1.446469546E-05
      24054.70c 3.593339471E-06
      25055.70c 8.034547803E-05
      26054.70c 2.922665002E-05
      26056.70c 4.583832776E-04
      26057.70c 1.059152543E-05
      26058.70c 1.398878126E-06
      29063.70c 2.340631425E-04
      29065.70c 1.043252115E-04
      92234.70c 7.088911783E-05
      92235.70c 6.606867629E-03
      92236.70c 2.835584689E-05
      92238.70c 3.828013112E-04
mt306    lwtr.60t
c      total atom density =  8.00555E-02 a/b-cm
```

```
m307     $  8.005550E-02
        1001.70c 4.152545507E-01
        8016.70c 2.220098021E-01
        12024.70c 1.320159564E-03
        12025.70c 1.671303571E-04
        12026.70c 1.840099023E-04
        13027.70c 3.529964722E-01
        14028.70c 1.261537714E-03
        14029.70c 6.387695590E-05
        14030.70c 4.240222209E-05
        22046.70c 5.249634754E-06
        22047.70c 4.734217159E-06
        22048.70c 4.690947164E-05
        22049.70c 3.442487881E-06
        22050.70c 3.296126872E-06
        24050.70c 6.626867242E-06
        24052.70c 1.276477354E-04
        24053.70c 1.447246438E-05
        24054.70c 3.595269438E-06
        25055.70c 8.101644589E-05
        26054.70c 2.960359702E-05
        26056.70c 4.642967934E-04
        26057.70c 1.072816079E-05
        26058.70c 1.416929960E-06
        29063.70c 2.362799068E-04
        29065.70c 1.053132228E-04
        92234.70c 5.555422712E-05
        92235.70c 5.177659664E-03
        92236.70c 2.222184074E-05
        92238.70c 2.999932262E-04
mt307     lwtr.60t
c       total atom density =  8.00271E-02 a/b-cm
m308     $  8.002710E-02
        1001.70c 4.154017194E-01
        8016.70c 2.193781522E-01
        12024.70c 1.320627436E-03
        12025.70c 1.671895891E-04
        12026.70c 1.840751165E-04
        13027.70c 3.564791884E-01
        14028.70c 1.269457278E-03
        14029.70c 6.427834092E-05
        14030.70c 4.266866449E-05
        22046.70c 5.251495256E-06
        22047.70c 4.735894994E-06
        22048.70c 4.692609664E-05
        22049.70c 3.443707919E-06
```

```
        22050.70c 3.297295039E-06
        24050.70c 6.629215843E-06
        24052.70c 1.276929746E-04
        24053.70c 1.447759351E-05
        24054.70c 3.596543623E-06
        25055.70c 8.146026792E-05
        26054.70c 2.985300775E-05
        26056.70c 4.682075734E-04
        26057.70c 1.081853357E-05
        26058.70c 1.428865754E-06
        29063.70c 2.377469270E-04
        29065.70c 1.059668376E-04
        92234.70c 4.541111007E-05
        92235.70c 4.232315658E-03
        92236.70c 1.816459398E-05
        92238.70c 2.452193946E-04
mt308     lwtr.60t
c       total atom density =  8.00013E-02 a/b-cm
m309     $  8.000130E-02
        1001.70c 4.155354944E-01
        8016.70c 2.169850918E-01
        12024.70c 1.321052728E-03
        12025.70c 1.672434304E-04
        12026.70c 1.841343956E-04
        13027.70c 3.596464366E-01
        14028.70c 1.276678476E-03
        14029.70c 6.464391015E-05
        14030.70c 4.291140154E-05
        22046.70c 5.253186435E-06
        22047.70c 4.737420130E-06
        22048.70c 4.694120860E-05
        22049.70c 3.444816923E-06
        22050.70c 3.298356892E-06
        24050.70c 6.631350700E-06
        24052.70c 1.277340965E-04
        24053.70c 1.448225584E-05
        24054.70c 3.597701845E-06
        25055.70c 8.186386983E-05
        26054.70c 3.007986787E-05
        26056.70c 4.717645464E-04
        26057.70c 1.090072872E-05
        26058.70c 1.439713227E-06
        29063.70c 2.390809693E-04
        29065.70c 1.065613284E-04
        92234.70c 3.618501495E-05
        92235.70c 3.372443143E-03
```

```
      92236.70c 1.447413098E-05
      92238.70c 1.953992057E-04
mt309     lwtr.60t
c
c
c       Region IV Control Element Material Descriptions
c      ------------------------------------------------
c
c        Aluminum clad of control elements
m21      13027.70c  5.85482E-02   1001.70c  3.45716E-04  12024.70c  5.28432E-04
        12025.70c  6.68986E-05  12026.70c  7.36554E-05  14028.70c  3.20373E-04
        14029.70c  1.62219E-05  14030.70c  1.07683E-05  22046.70c  2.10131E-06
        22047.70c  1.89500E-06  22048.70c  1.87768E-05  22049.70c  1.37795E-06
        22050.70c  1.31937E-06  24050.70c  2.65258E-06  24052.70c  5.10942E-05
        24053.70c  5.79300E-06  24054.70c  1.43910E-06  25055.70c  2.21974E-05
        26054.70c  5.96144E-06  26056.70c  9.34978E-05  26057.70c  2.16039E-06
        26058.70c  2.85334E-07  29063.70c  6.04931E-05  29065.70c  2.69626E-05
c
c      Inner Control Element
c
c        Inner control element--Gray Ta-Al/H2O region
m400     73181.70c  2.10142E-02  13027.70c  3.43728E-02   1001.70c  3.27118E-03
        8016.70c  1.63559E-03
mt400    lwtr.60t
c        Inner control element--black EuO-Al region
m401     63151.70c  4.04205E-03  63153.70c  4.41415E-03  13027.70c  4.01816E-02
        8016.70c  1.26843E-02
c        Inner control element-upper Al/H2O region
m402     1001.70c  3.26363E-03   8016.70c  1.63181E-03  13027.70c  5.72947E-02
mt402    lwtr.60t
c        Inner control element-lower Al/H2O region
m403     1001.70c  3.19976E-03   8016.70c  1.59988E-03  13027.70c  5.73524E-02
mt403    lwtr.60t
c
c      Outer Control Element
c
c        Outer control element--Gray Ta-Al/H2O region
m411     73181.70c  2.10212E-02  13027.70c  3.43843E-02   1001.70c  3.24993E-03
        8016.70c  1.62497E-03
mt411    lwtr.60t
c        Outer control element--black EuO-Al region
m410     63151.70c  4.04205E-03  63153.70c  4.41415E-03  13027.70c  4.01816E-02
        8016.70c  1.26843E-02
c        Outer control element-upper Al/H2O region
m412     1001.70c  3.01443E-03   8016.70c  1.50722E-03  13027.70c  5.75198E-02
mt412    lwtr.60t
```

```
c       Outer control element-lower Al/H2O region
m413     1001.70c  3.19012E-03   8016.70c  1.59506E-03  13027.70c  5.73611E-02
mt413    lwtr.60t
c
c
c       Region V Removable  Reflector Material Descriptions
c       ---------------------------------------------------
c
c        Water above removable reflector region --Density= 0.9794 g/cm^3
m4        1001.70c     6.59947E-02    8016.70c    3.29974E-02
mt4       lwtr.60t
c        Water gaps in removable reflector region --Avg. Density= 0.98465 g/cm^3
m5        1001.70c     6.63485E-02    8016.70c    3.31742E-02
mt5       lwtr.60t
c        Water below removable reflector region --Density= 0.9899 g/cm^3
m6        1001.70c     6.67022E-02    8016.70c    3.33511E-02
mt6       lwtr.60t
c
c       Aluminum clad of removable refl. reg.
m22       13027.70c  5.85482E-02   1001.70c  3.45716E-04  12024.70c  5.28432E-04
        12025.70c  6.68986E-05  12026.70c  7.36554E-05  14028.70c  3.20373E-04
        14029.70c  1.62219E-05  14030.70c  1.07683E-05  22046.70c  2.10131E-06
        22047.70c  1.89500E-06  22048.70c  1.87768E-05  22049.70c  1.37795E-06
        22050.70c  1.31937E-06  24050.70c  2.65258E-06  24052.70c  5.10942E-05
        24053.70c  5.79300E-06  24054.70c  1.43910E-06  25055.70c  2.21974E-05
        26054.70c  5.96144E-06  26056.70c  9.34978E-05  26057.70c  2.16039E-06
        26058.70c  2.85334E-07  29063.70c  6.04931E-05  29065.70c  2.69626E-05
c
c       Aluminum liners in Be reflectors also outside Be reflector container
m24       13027.70c  5.85482E-02   1001.70c  3.45716E-04  12024.70c  5.28432E-04
        12025.70c  6.68986E-05  12026.70c  7.36554E-05  14028.70c  3.20373E-04
        14029.70c  1.62219E-05  14030.70c  1.07683E-05  22046.70c  2.10131E-06
        22047.70c  1.89500E-06  22048.70c  1.87768E-05  22049.70c  1.37795E-06
        22050.70c  1.31937E-06  24050.70c  2.65258E-06  24052.70c  5.10942E-05
        24053.70c  5.79300E-06  24054.70c  1.43910E-06  25055.70c  2.21974E-05
        26054.70c  5.96144E-06  26056.70c  9.34978E-05  26057.70c  2.16039E-06
        26058.70c  2.85334E-07  29063.70c  6.04931E-05  29065.70c  2.69626E-05
c
c       Beryllium plugs
m33        4009.70c  1.23606E-01   1001.70c  6.73828E-07   8016.70c  3.36914E-07
mt33      be.60t
c
c       Eu Liner in RB-7A
m38       26054.70c  3.78706E-03  26056.70c  5.93954E-02  26057.70c  1.37241E-03
        26058.70c  1.81261E-04  63000.42c  8.28076E-03   8016.70c  1.24211E-02
c
```

```
c        Eu  in RB-7A
m39      26054.70c  2.00939E-03  26056.70c  3.15148E-02  26057.70c  7.28190E-04
         26058.70c  9.61761E-05   5010.70c  6.33141-5    63000.42c   2.36096E-04
          8016.70c  3.54144E-04  13027.70c  1.03881-3
c
c      Beryllium removable reflector
c        At the start of cycle 400, a new removable beryllium reflector was placed in the reactor
c        No Li-6, or He-3 present (100% Be - H2O gaps are explicitly modelled)
c
m101      4009.70c  1.23607E-01    $ Removable reflector Rgn 1 material
mt101     be.60t
m102      4009.70c  1.23607E-01    $ Removable reflector Rgn 2 material
mt102     be.60t
m103      4009.70c  1.23607E-01    $ Removable reflector Rgn 3 material
mt103     be.60t
m104      4009.70c 1.23607E-01  3006.70c 3.14456-7  2003.70c 9.25940-9 $semi-permanent
refl. reg
mt104     be.60t
c
c       Region VI  Permanent  Reflector Material
c      -----------------------------------------
c
c         Water in Irradiation Facilities  - Density= 0.98465 g/cc
m9        1001.70c     6.63485E-02    8016.70c    3.31742E-02
mt9       lwtr.60t
c
c        Beryllium permanent reflector(with he-3 and li-6)
m105     4009.70c  1.21135E-01   1001.70c   1.34766E-03   8016.70c   6.73828E-04
         3006.70c  1.74120E-7    2003.70c   5.11969E-9
mt105    be.60t
m106     4009.70c   1.21135E-01   1001.70c   1.34766E-03   8016.70c  6.73828E-04
         3006.70c   1.08525E-7    2003.70c   4.29666E-9
mt106    be.60t
m107     4009.70c   1.21135E-01   1001.70c   1.34766E-03   8016.70c  6.73828E-04
         3006.70c   7.10578E-8    2003.70c   2.07747E-9
mt107    be.60t
m108     4009.70c   1.21135E-01   1001.70c   1.34766E-03   8016.70c  6.73828E-04
         3006.70c   4.80664E-8    2003.70c   1.39911E-9
mt108    be.60t
m109     4009.70c   1.21135E-01   1001.70c   1.34766E-03   8016.70c  6.73828E-04
         3006.70c   3.32031E-8    2003.70c   9.59631E-10
mt109    be.60t
m110     4009.70c   1.21135E-01   1001.70c   1.34766E-03   8016.70c  6.73828E-04
         3006.70c   2.46752E-8    2003.70c   7.06338E-10
mt110    be.60t
m111     4009.70c   1.21135E-01   1001.70c   1.34766E-03   8016.70c  6.73828E-04
```

```
        3006.70c   1.84489E-8    2003.70c   5.19306E-10
mt111    be.60t
c
c       H-Tube material                         Total =   6.03240E-02
m520     13027.70c  6.00625E-02  14028.70c   1.33983E-04  14029.70c  6.78416E-06
        14030.70c  4.50340E-06  25055.70c   7.42655E-06
        26054.70c  4.27394E-06  26056.70c   6.70314E-05  26057.70c  1.54885E-06
        26058.70c  2.04565E-07  29063.70c   2.47400E-05  29065.70c  1.10270E-05
c       H-Tube clad
m521     13027.70c   6.02423E-02
c
c       Water Reflector --Density= 0.9899 g/cm^3
m7        1001.70c     6.67022E-02    8016.70c    3.33511E-02
mt7       lwtr.60t
c        H2O Pool  --Density= 1.0000 g/cm^3
m8        1001.70c     6.73828E-02    8016.70c    3.36914E-02
mt8       lwtr.60t
c
c       Pressure Vessel Stainless steel liner - SCALE SS304 (69.5 w/o Fe, 19.0 w/o Cr,
c                                               9.5 w/o Ni,  2.0 w/o Mn)
c       also used for ss liners in vxfs
m40      26054.70c  3.47221E-03  26056.70c  5.44574E-02  26057.70c  1.25831E-03
        26058.70c  1.66191E-04  24050.70c  7.58122E-04  24052.70c  1.46030E-02
        24053.70c  1.65567E-03  24054.70c  4.11303E-04
        28058.70c  5.25498E-03  28060.70c  2.02388E-03  28061.70c  8.79947E-05
        28062.70c  2.80194E-04  28064.70c  7.17851E-05  25055.70c  1.73629E-03
c
c       Carbon steel PV -- SCALE Carbon Steel (99.0 w/o Fe, 1.0 w/o C)
m50      26054.70c  4.88433E-03  26056.70c  7.66047E-02  26057.70c  1.77005E-03
        26058.70c  2.33780E-04   6000.70c   3.92134E-03
c
c       Air Void in reflector components
m60      1001.70c   1.00000-15   8016.70c   1.00000-15
c
c     Barytes concrete at 3.09725 g/cc (used for biological shield); shown below are
atoms/(barn*cm) by nuclide
m62       1001.70c 1.681E-2    5010.70c 3.378e-4    5011.70c 1.368e-3
         8016.70c 4.195E-2   11023.70c 3.193e-4   12024.70c 1.22356E-04
        12025.70c 1.54900E-5 12026.70c 1.70545E-5
        13027.70c 7.534e-4   14028.70c 1.16210E-3 14029.70c 5.88420E-05
        14030.70c 3.90600E-5 16032.70c 5.401e-3
        20000.66c 3.273e-3   22046.70c 1.10220E-5 22047.70c 9.93984E-06
        22048.70c 9.84899E-5 22049.70c 7.22776E-6 22050.70c 6.92048E-06
        25055.70c 1.713e-4
        26054.70c 4.02188E-5 26056.70c 6.30781E-4 26057.70c 1.45750E-05
        26058.70c 1.92500E-6 56138.70c 5.394e-3
```

```
c       real concentration for ba-138 = 3.8787e-3 atoms/(barn*cm); it is available;
c       other nuclide concentrations for which there is no mcnp xsect data:
c       ba-134=1.3037e-4;  ba-135=3.5557e-4;  ba-136=4.2364e-4;  ba-137=6.0575e-4
c       total number density for all barium nuclides in barytes concrete: 5.394030e-3
c       total number density for all nuclides in barytes concrete:  7.801382e-2
c       while this barytes concrete (for ANS project) was 3.09725 g/cc, it can
c       sometimes be made as dense as 3.5 g/cc; see book by Schaffer
c
c       Replace with 1014.51c and parah.96t
c       Liquid H at 20 deg.K, 15 bar pressure; Total = 0.04372 atoms/(b*cm) = 0.0726 g/cc
(revised as per Trevor Lucas, 5-3-96)
m560     1001.70c  0.04372
c mt560    hpara.60t
c
c       Ti-4V-6Al TEM Holder Material from Ron's e-mail
m532     13027 -0.0632
         26054 -0.000113
         26056 -0.00184
         26057 -0.000043
         26058 -0.000006
         6012  -0.0001
         1001  -0.00005
         23000 -0.0379
         8016  -0.001696
         8017  -0.000001
         7014  -0.009958
         7015  -0.000042
         39089 -0.01
         22046 -0.070947
         22047 -0.065372
         22048 -0.661551
         22049 -0.049559
         22050 -0.048423
c
c       Gadolinium in target rabbit  (Natural Gd Vector)
m533     64159     -2.906E-04
         64153     -9.691E-04
         63154     -3.556E-05
         63155     -6.076E-06
         62153     -1.481E-09
         64151     -1.898E-08
         63152     -2.114E-09
         62151     -4.348E-09
         64152     -7.917E-03
         62149     -1.466E-09
         64154     -1.086E-01
```

```
        63151     -9.966E-10
        63153     -2.190E-04
        62150     -4.439E-08
        64155     -1.063E-02
        64156     -1.811E+00
        62152     -2.586E-08
        64157     -3.076E-04
        64158     -2.103E+00
        65159     -9.770E-03
        66160     -1.024E-04
        62154     -1.851E-08
        66161     -1.275E-03
        64160     -1.129E+00
        66162     -2.715E-04
        66163     -6.672E-05
        66164     -5.589E-06
c
c        TEM Target Material (Areva DUO2 Impurity Report & forced isotopes)
m534     92239     -8.465E-07
        93239     -1.211E-04
        92237     -5.164E-07
        93238     -3.165E-08
        94241     -6.644E-05
        94239     -1.139E-03
        94240     -1.021E-04
        94238     -1.929E-07
        92238     -7.940E-02
        94242     -2.575E-06
        92234     -6.997E-07
        93237     -1.876E-06
        92236     -8.220E-06
        92235     -1.782E-04
        53135     -2.465E-07
        54133     -4.119E-06
        42099     -1.509E-06
        52132     -2.211E-06
        44105     -9.586E-08
        58143     -8.129E-07
        45105     -5.101E-07
        56140     -5.678E-06
        57140     -6.701E-07
        53131     -2.980E-06
        59143     -4.189E-06
        44103     -6.833E-06
        58141     -7.170E-06
        54135     -6.830E-08
```

60147	-2.059E-06
61149	-3.959E-07
40095	-5.235E-06
61151	-1.192E-07
62153	-1.589E-07
39091	-2.767E-06
38089	-1.922E-06
52127	-1.807E-08
41095	-6.616E-07
47111	-1.573E-07
58144	-7.261E-06
44106	-5.293E-06
63156	-2.772E-07
63157	-1.069E-08
61148	-5.760E-08
55136	-1.082E-07
50125	-4.623E-08
61147	-1.633E-06
53130	-6.753E-10
55137	-1.269E-05
59142	-4.937E-10
38090	-3.192E-06
39090	-7.514E-10
55134	-2.304E-07
51125	-1.480E-07
51126	-1.844E-09
50123	-1.807E-08
36085	-1.620E-07
63155	-1.197E-07
37086	-4.283E-10
62151	-9.127E-07
63154	-6.848E-08
65160	-1.073E-09
51124	-6.462E-10
43099	-6.112E-06
63152	-1.711E-10
40093	-5.080E-06
50126	-3.281E-07
34079	-5.081E-08
55135	-5.967E-06
6014	-1.189E-09
46107	-3.955E-06
53129	-2.009E-06
41094	-1.595E-11
37087	-1.491E-06
62147	-5.351E-08

57138	-9.607E-11
60144	-6.458E-07
58142	-9.726E-06
62149	-3.399E-07
49115	-3.689E-08
60145	-5.817E-06
62148	-1.393E-07
48113	-1.594E-08
64152	-8.838E-11
34082	-2.540E-07
31069	-1.539E-11
31071	-7.152E-11
32072	-1.779E-10
32073	-3.052E-10
32074	-8.331E-10
32076	-3.938E-09
33075	-1.570E-09
34076	-1.174E-11
34077	-8.191E-09
34078	-2.153E-08
34080	-9.223E-08
35081	-1.733E-07
36082	-1.456E-09
36083	-3.656E-07
36084	-7.152E-07
36086	-1.097E-06
37085	-5.699E-07
38086	-2.585E-10
38087	-2.436E-11
38088	-1.908E-06
39089	-6.944E-07
40090	-6.490E-09
40091	-8.963E-07
40092	-4.115E-06
40094	-5.990E-06
40096	-6.526E-06
42095	-6.286E-07
42096	-1.465E-08
42097	-6.576E-06
42098	-7.335E-06
42100	-8.689E-06
44099	-2.027E-10
44100	-1.265E-07
44101	-8.004E-06
44102	-8.276E-06
44104	-8.559E-06

45103	-1.983E-06
46104	-2.164E-07
46105	-4.464E-06
46106	-1.539E-06
46108	-2.440E-06
46110	-7.526E-07
47109	-1.324E-06
48110	-1.215E-07
48111	-2.080E-07
48112	-1.680E-07
48114	-1.963E-07
48116	-7.476E-08
50115	-3.017E-09
50116	-1.256E-08
50117	-7.217E-08
50118	-6.096E-08
50119	-6.269E-08
50120	-5.860E-08
50122	-7.821E-08
50124	-1.385E-07
51121	-5.691E-08
51123	-6.658E-08
52122	-5.937E-10
52124	-1.563E-10
52125	-2.475E-09
52126	-3.983E-09
52128	-1.174E-06
52130	-4.272E-06
53127	-4.433E-07
54128	-4.383E-09
54130	-1.232E-08
54131	-3.553E-06
54132	-8.084E-06
54134	-1.465E-05
54136	-2.132E-05
55133	-7.824E-06
56134	-3.906E-09
56135	-2.653E-11
56136	-7.992E-08
56137	-3.085E-08
56138	-1.199E-05
57139	-1.073E-05
58140	-4.281E-06
59141	-2.927E-06
60142	-6.343E-09
60143	-3.422E-06

```
        60146    -5.432E-06
        60148    -3.785E-06
        60150    -2.009E-06
        62150    -1.948E-06
        62152    -1.390E-06
        62154    -6.053E-07
        63151    -1.570E-10
        63153    -8.209E-07
        64154    -2.830E-10
        64155    -1.027E-09
        64156    -1.831E-07
        64157    -5.004E-08
        64158    -2.403E-07
        64160    -2.157E-08
        65159    -4.762E-08
        66160    -1.502E-10
        66161    -6.266E-09
        66162    -5.886E-09
        66163    -4.046E-09
        66164    -1.536E-09
        67165    -8.135E-10
        68166    -4.415E-10
        68167    -1.052E-10
        68168    -1.520E-10
        8016     -1.129E-02
        8017     -4.572E-06
        8018     -6.128E-12
        7015     -3.003E-10
        6012     -5.453E-09
        6013     -1.398E-07
c
c       TEM Insulator Material  (ZrO2)
m536    41097    -6.751E-09
        40097    -9.495E-08
        40095    -9.460E-07
        41095    -2.405E-07
        39090    -1.413E-09
        40089    -1.019E-09
        41096    -1.010E-10
        39091    -1.574E-09
        40093    -3.647E-06
        40090    -3.763E-02
        40091    -8.287E-03
        40092    -1.284E-02
        39089    -1.731E-08
        38086    -3.050E-11
```

```
      38087     -5.158E-10
      38088     -2.171E-09
      42095     -4.293E-07
      40094     -1.328E-02
      42096     -7.699E-09
      40096     -2.182E-03
      42097     -2.874E-06
      42098     -7.569E-09
      8016      -2.603E-02
      8017      -1.000E-09
      7015      -7.470E-10
      6012      -1.342E-08
      6013      -3.243E-07
c
c ---------------------------------------------------------------
LOST   500 500
DBCN   5
mode n
kcode  100000 1.0 100 10100
sdef erg=d1 axs=0 0 1 rad=d2 ext=d3
sp1 -3 0.988 2.249
si2  0  7.140  8.960  10.780  12.600  15.130  16.592  18.054  19.516  20.978
sp2  0  0.092  0.113   0.133   0.000   0.145   0.159   0.172   0.186   0.000
si3 -25 25
sp3 -21 0
c F4:N    534
c F14:N   537
c F24:N   538
c E0   1.00E-10 5.00E-10 7.50E-10 1.00E-09 1.20E-09 1.50E-09 2.00E-09 &
c      2.50E-09 3.00E-09 4.00E-09 5.00E-09 7.50E-09 1.00E-08 2.53E-08 3.00E-08 &
c      4.00E-08 5.00E-08 6.00E-08 7.00E-08 8.00E-08 9.00E-08 1.00E-07 1.25E-07 &
c     1.50E-07 1.75E-07 2.00E-07 2.25E-07 2.50E-07 2.75E-07 3.00E-07 3.25E-07 &
c     3.50E-07 3.75E-07 4.00E-07 4.50E-07 5.00E-07 5.50E-07 6.00E-07 6.25E-07 &
c     6.50E-07 7.00E-07 7.50E-07 8.00E-07 8.50E-07 9.00E-07 9.25E-07 9.50E-07 &
c     9.75E-07 1.00E-06 1.01E-06 1.02E-06 1.03E-06 1.04E-06 1.05E-06 1.06E-06 &
c     1.07E-06 1.08E-06 1.09E-06 1.10E-06 1.11E-06 1.12E-06 1.13E-06 1.14E-06 &
c     1.15E-06 1.18E-06 1.20E-06 1.23E-06 1.25E-06 1.30E-06 1.35E-06 1.40E-06 &
c     1.45E-06 1.50E-06 1.59E-06 1.68E-06 1.77E-06 1.86E-06 1.94E-06 2.00E-06 &
c     2.12E-06 2.21E-06 2.30E-06 2.38E-06 2.47E-06 2.57E-06 2.67E-06 2.77E-06 &
c     2.87E-06 2.97E-06 3.00E-06 3.05E-06 3.15E-06 3.50E-06 3.73E-06 4.00E-06 &
c     4.75E-06 5.00E-06 5.40E-06 6.00E-06 6.25E-06 6.50E-06 6.75E-06 7.00E-06 &
c     7.15E-06 8.10E-06 9.10E-06 1.00E-05 1.15E-05 1.19E-05 1.29E-05 1.38E-05 &
c     1.44E-05 1.51E-05 1.60E-05 1.70E-05 1.85E-05 1.90E-05 2.00E-05 2.10E-05 &
c     2.25E-05 2.50E-05 2.75E-05 3.00E-05 3.13E-05 3.18E-05 3.33E-05 3.38E-05 &
c     3.46E-05 3.55E-05 3.70E-05 3.80E-05 3.91E-05 3.96E-05 4.10E-05 4.24E-05 &
c     4.40E-05 4.52E-05 4.70E-05 4.83E-05 4.92E-05 5.06E-05 5.20E-05 5.34E-05 &
```

```
c     5.90E-05 6.10E-05 6.50E-05 6.75E-05 7.20E-05 7.60E-05 8.00E-05 8.20E-05 &
c     9.00E-05 1.00E-04 1.08E-04 1.15E-04 1.19E-04 1.22E-04 1.86E-04 1.93E-04 &
c     2.08E-04 2.10E-04 2.40E-04 2.85E-04 3.05E-04 5.50E-04 6.70E-04 6.83E-04 &
c     9.50E-04 1.15E-03 1.50E-03 1.55E-03 1.80E-03 2.20E-03 2.29E-03 2.58E-03 &
c     3.00E-03 3.74E-03 3.90E-03 6.00E-03 8.03E-03 9.50E-03 1.30E-02 1.70E-02 &
c     2.50E-02 3.00E-02 4.50E-02 5.00E-02 5.20E-02 6.00E-02 7.30E-02 7.50E-02 &
c     8.20E-02 8.50E-02 1.00E-01 1.28E-01 1.50E-01 2.00E-01 2.70E-01 3.30E-01 &
c     4.00E-01 4.20E-01 4.40E-01 4.70E-01 5.00E-01 5.50E-01 5.73E-01 6.00E-01 &
c     6.70E-01 6.79E-01 7.50E-01 8.20E-01 8.61E-01 8.75E-01 9.00E-01 9.20E-01 &
c     1.01E+00 1.10E+00 1.20E+00 1.25E+00 1.32E+00 1.36E+00 1.40E+00 1.50E+00 &
c     1.85E+00 2.35E+00 2.48E+00 3.00E+00 4.30E+00 4.80E+00 6.43E+00 8.19E+00 &
c     1.00E+01 1.28E+01 1.38E+01 1.46E+01 1.57E+01 1.73E+01 2.00E+01
c --------------------------------------------------------------
```